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SOME INTERRELATIONS OF SCIENCE, TECHNOLOGY, AND THE PHOTOGRAPHIC INDUSTRY IN THE NINETEENTH CENTURY

A thesis submitted to the Graduate School of the University of Wisconsin in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

by

Reese Valmer Jenkins

Degree to be awarded

January 19—

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To Professors: Ihde

Hiebert

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This thesis having been approved in respect to form and mechanical execution is referred to you for judgment upon its substantial merit.

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Approved as satisfying in substance the doctoral thesis requirement of the University of Wisconsin.

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REESE VALMER JENKINS

A thesis submitted in partial fulfillment
of the requirements for the degree of

DOCTOR OF PHILOSOPHY
(History of Science)
at the
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INTRODUCTION

During the twentieth century there has developed an increasing awareness of the influence of science and technology on society. One of the major areas in which this influence is most apparent is industry, where mass production and product innovation have been increasingly important to the growth of firms and where companies have become dependent for their economic survival upon scientific research and development. Though the impact of science has been most clearly recognized in the twentieth century, it certainly began prior to this time. An examination of the role of science in industrial development during the nineteenth century may provide perspective in assessing the mechanisms of interaction between science and economic institutions today.

It is the purpose of this study to examine a specific case of the interaction of science and industry, namely, the influence of chemical and optical science on the growth and structure of the photographic industry during the nineteenth century. The impact of science on industry manifests itself in at least two important ways. First, science indirectly influences industry through technology. Since the state of science at a given time can set a limit on the degree of progress in technology, it is important

to examine the interrelationship of science and technology in order to assess the degree of dependence of technology on scientific developments. Then, by examining the dependence of the development of the industry upon the state of technology, one can gain some conception of the indirect influence of science on industry. Second, science can directly affect industry through the influence of scientifically trained personnel and through the provision of industrial research facilities. The administrative attitudes of personnel and the product developments from industrial laboratories may strongly influence the economic position of production firms.

This study is divided into two parts. In the first part, the relationship between science and photographic technology will be examined. The aim is not to be comprehensive but to examine a few of the significant advances in photographic technology and determine what, if any, role scientific institutions or scientists played in their development. In the second part, the growth and structure of the photographic industry will be examined, with an emphasis placed upon the influence of photographic technology, scientific personnel, and industrial research facilities. Because of easier access to American sources of industrial history and primary materials, the emphasis will fall upon the American industry, although attention will also be paid to developments in Germany, Great Britain,

and France. This built-in bias will be offset by two compensating factors. First, the general sources in the history of photography which have casually mentioned industrial firms have focused in particular on those in Germany, Great Britain, and France. Second, the American photographic industry, by the admission of historians, was strong both during the period of popularity of the daguerreotype and during the last decade of the century. Therefore, emphasis on the American industry may not be totally inappropriate. This study does not aim to provide a comprehensive industrial history but instead to describe general trends and focus upon those firms which developed an interest in scientific research and personnel.

The study of the relationship involving science, technology, and the photographic industry during the nineteenth century reveals five major phases in technical developments: (1) an embryonic phase, in which basic requisite ideas and processes accumulated until the announcement of a practical process in 1839; (2) the daguerreotype phase, from 1839 to 1855, during which direct positive photography was popular; (3) the wet collodion phase, from 1855 to 1880, during which wet collodion glass negative plate photography was commonly used; (4) the gelatin dry plate phase, from 1880, during which amateur photography began; and (5) the celluloid film phase, from 1890, during which amateur photographers

entered the field in large numbers and the output of industry grew substantially. Though patterns of production of photographic paper and cameras did not always follow exactly the sequence of development of photosensitive materials for the camera, this pattern was sufficiently dominant to influence strongly the form of development in the other areas of production in the industry.

There already exist a number of good works on the history of photography. One of the best technical histories is Joseph M. Eder's Geschichte der Photographie, (translated by Edward Epstean, History of Photography). In spite of its age (1932), occasional errors of fact and of translation, and definite Austrian-German bias, the work is a classic study of the history of photographic technology by a man who worked in the field and directed a scientific school of photography in Vienna from 1880 until the early 1930's. Wolfgang Baier's recent work (1964), Quellendarstellungen zur Geschichte der Fotographie, is a more abridged account of the history of photography but provides numerous excerpts from original sources. Both Eder and Baier give special emphasis to the German developments in photography. Helmut and Alison Gernsheim have provided a recent (1955), somewhat non-technical work, The History of Photography..., which emphasizes the work of British pioneers in photog-

raphy. Robert Taft in 1937 provided the only significant study of American photography, Photography and the American Scene, 1839-1889. This is a well-documented work but does not emphasize technical developments. Beaumont Newhall has written several accounts of the history of photography from an American point of view, but he mentions technical developments in only a cursory way while focusing on the esthetic and artistic history of photography. None of the above-mentioned works deals to any extent with the history of the photographic industry, though they and several other works occasionally mention specific companies and in special cases provide information not otherwise available in this country. Fortunately, Albert Boni's excellent and highly comprehensive bibliography, Photographic Literature, an International Bibliographic Guide, was completed in 1962 and provided valuable guidance for this study.

This study differs from the works mentioned above, none of which has focused on either the direct influence of science on photographic technology or on the development of the photographic industry and its relationship to science and technology. Where, for example, Eder has sought to treat comprehensively the history of photographic technology, this study endeavors to select only a limited number of significant advances and place their development within their contemporary scientific setting. Such

themes as the degree of dependency of photographic technology upon science and the role of scientific and technical journals in the progress of the technology may then be assessed. Particular emphasis has been placed on those instances where scientifically trained personnel were directly involved in industrial developments. Furthermore, an examination of the early development of some industrial research laboratories in the photographic industry will provide a view of them during their infancy. It is hoped that an awareness of some trends may emerge from this investigation and thereby provide further understanding of the relationship between science and industry during this early period of their conscious awareness of each other.

PART I

Chapter II

EARLY CHEMICAL DEVELOPMENTS

During the late eighteenth and early nineteenth centuries, growing knowledge and understanding of chemical substances and their composition laid the foundation for the discovery in 1839 of a practical photographic process and for the progressive reduction in required exposure time during the remainder of the century. The key elements in this reduction of exposure time include the discovery of the latent image, the introduction of sodium thiosulfate as an effective fixing agent, the use of highly sensitive gelatin bromide emulsions, and the discovery and synthesis of efficient developing agents. Both the original discovery and the subsequent advance of photography resulted in large part from fortuitous findings; yet each step forward depended upon earlier advances in scientific knowledge and theory.

In preparing the way for the discovery and progress of photography, the investigation of the light sensitivity of silver salts played the most important role. Among the earliest observers of this property of certain silver salts were Angelo Sala and Wilhelm Homberg (1652-1715), who in 1614 and 1694, respectively, noted that the sun's rays darkened silver nitrate. Disagreement

arose regarding the cause of the action, with Robert Boyle (1627-1671) attributing it to the air while eighteenth century philosophers debated between heat and light as the agents. Johann Heinrich Schulze (1687-1744), while investigating phosphorescence, stumbled upon the light sensitivity of silver salts. As reported in a treatise published in 1727, he exposed a paste probably containing the nitrate, chloride, and carbonate of silver, observed the darkening action, and concluded that light was the principal agent. Later in the same century chemical philosophers such as William Lewis (1714-1781), Carl W. Scheele (1742-1786), and Joseph Priestly (1733-1804) learned of Schulze's work and conducted further investigations of silver salts. During the last quarter of the eighteenth century, use of silver salts for recording outlines was described in at least two popular works of scientific entertainment.[1]

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1. See Helmut and Alison Gernsheim, The History of Photography... (London, 1955), pp. 20-25; see also Josef Maria Eder, Geschichte der Photographie (4th ed., Halle, 1932), Vol. I, pp 32-113; or Eder, History of Photography, trans. by Edward Epstean (New York, 1945), pp. 22-85. Eder treats in detail the early history of photochemistry. In addition, he wrote an extensive biography of Schulze, Johann Heinrich Schulze, 1917. The two popular works referred to are Guyot, Nouvelles Récréations, 1769-1770, in 4 vol.; and William Hooper, Rational Récréations, 1774, in 4 vol. (later editions in 1782, 1783, and 1787). The Hooper work is a virtual translation of that of Guyot.

During this same period, questions regarding the nature and effect of heat and light attracted the attention of numerous investigators and helped stimulate interest in spectrum studies. Scheele, in Chemische Abhandlung von der Luft und Feuer (1777), observed that horn silver, a naturally occurring form of silver chloride known since the late sixteenth century, when exposed to the solar spectrum, responds differently to each color region, with the greatest darkening occurring at the violet end of the spectrum. Furthermore, he argued that the darkening is due to the formation of metallic silver. Though his explanation rested upon phlogistic principles, his conclusion was basically correct.[2] He also pointed out that an ammonia solution dissolves horn silver. Other investigators interested in spectrum studies turned to silver chloride as a recording tool. Jean Senebier (1742-1809) in 1782 measured the exposure time required for light of different colors to darken silver chloride, while both J. W. Ritter (1776-1810) in 1801 and William Hyde Wollaston (1766-1828) in 1802 detected the ultraviolet region of the spectrum by means of silver chloride darkening. Joseph Black's (1728-1799) chemical

2. Carl Wilhelm Scheele, Chemische Abhandlung von Luft und Feuer... (Leipzig, 1782), pp. 65-69; The Collected Papers of Carl Wilhelm Scheele, ed. by Leonard Dobbin, Section II, Chemical Treatise on Air and Fire (London, 1931), pp. 126-127.

lectures at the University of Edinburgh, published posthumously, indicate that he spoke of Scheele's spectrum studies and that, like Scheele, he concluded that light reduced the silver salt to the metallic state.[3] By the beginning of the nineteenth century, then, most observers seriously interested in chemical philosophy probably knew of the light sensitivity of silver chloride and silver nitrate.

Early in the new century Journals of the Royal Institution carried an important and influential paper[4] by Thomas Wedgwood (1771-1805) and Humphry Davy (1778-1829), in which these two men reported on attempts to record by means of silver salts outlines, shadows, and camera obscura images. The initial impetus for the investigation had come from Wedgwood, the son of the famous English potter, Josiah Wedgwood (1730-1795). The younger Wedgwood had obtained early instruction from

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3. The work of Senebier, Ritter, and Wollaston was generally known at the time and referred to in a footnote to the Wedgwood paper by H. Davy. See John Davy, ed., The Collected Works of Sir Humphry Davy (London, 1839), Vol. II, p. 241. For reference to Black's lectures see Gernsheim, p. 24.

4. T. Wedgwood and H. Davy, "An Account of a Method of Copying Paintings Upon Glass, And of Making Profiles By the Agency of Light Upon the Nitrate of Silver. Invented by T. Wedgwood, Esq. with Observations by H. Davy," in Journals of the Royal Institution, II (1802). See the paper in The Collected Works of Sir Humphry Davy, ed. by John Davy (London, 1839), Vol II, pp. 240-245.

a tutor, Alexander Chisholm, a chemical assistant to William Lewis, who concerned himself with chemical matters and who had, according to his notebooks, repeated Schulze's experiments. In addition to this contact with someone concerned with chemical problems, Wedgwood included among his friends Joseph Priestley and Humphry Davy. Initially, Wedgwood intended to record camera obscura images on white paper or leather which had been treated with silver nitrate; however, he observed that the light was not strong enough to leave an imprint in any reasonable exposure period and, therefore, turned to copying shadows of objects and paintings on glass in broad daylight. In these experiments he observed that sunlight acts more rapidly upon silver salts which are on leather than upon those which are on paper. Davy repeated part of Wedgwood's work and added a few experiments of his own. He used the solar microscope and focused images upon a screen treated with a silver salt. He observed that muriate of silver is more sensitive than silver nitrate and that either salt is more sensitive when wet than when dry. Both investigators, nevertheless, encountered a major difficulty, the need for a suitable fixing agent, that is, a means of removing the unexposed salt so that it would not likewise darken when brought into the light for viewing. Scheele, of course, had mentioned that ammonia dissolves silver chloride, and it was known that silver nitrate is water

soluble, but apparently this knowledge did not help Wedgwood and Davy.[5]

The question of why Davy failed to obtain a fixing agent for silver chloride has puzzled historians of photography and led them to conclude that either the problem did not interest him or that details of Scheele's report had escaped his memory.[6] There may have been other reasons. Wedgwood had found that water did not remove water-soluble silver nitrate once it was coated on paper.[7] When Davy repeated Wedgwood's efforts with the same results, he concluded that silver salts united with the organic fibers of the paper and leather, forming an insoluble organo-silver compound.[8] This conclusion may have dissuaded

5. John Davy, pp. 240-245; Gernsheim, p. 22.

6. Eder assumes that Davy either neglected to acquaint himself with the work of Scheele (a position totally untenable in view of Davy's footnote, see note #3 above) or forgot the passage from Scheele. See Eder, Geschichte..., Vol. I, p. 183. Gernsheim assumes that Davy was uninterested in Wedgwood's experiments and only published them to oblige a friend. (If that were true, one might ask why Davy bothered to repeat Wedgwood's experiments and even extend them). See Gernsheim, p. 33.

7. John Davy, p. 242. The question might arise why Wedgwood was unable to remove the silver nitrate with water. Two possibilities come to mind. First, if he failed to wash with distilled water, his water no doubt contained a small quantity of chloride ion (and only a trace is necessary) and therefore could have produced the insoluble silver chloride which he then could not have removed. Second, since he was using white paper and leather and bleaching was carried out with chlorine by this time, the possibility of a residue of chlorine on the surface of the paper and leather might also have encouraged the formation of the insoluble silver chloride.

8. John Davy, p. 244.

him from using ammonia on the silver chloride, if he figured that a similar reaction occurred between the silver compound and the paper. He suggested that he hoped to return to this problem, but his very busy schedule of lectures at the Royal Institution and a new interest in galvinism and electrochemistry drew his attention instead.[9] Wedgwood did not pursue the matter further because of failing health. Though these efforts floundered for want of a fixing agent, the work of Wedgwood and Davy represents the first early efforts to obtain images in a camera obscura. Their report was widely circulated and thirty years later stimulated interest in the problem anew.[10]

Shortly after publication of the Wedgwood-Davy paper, Thomas Young (1773-1829), lecturer at the Royal Institution and, with Davy, co-editor of Journals, adopted some of the Wedgwood-Davy techniques. In his studies of light interference and the wave theory of light, Young, by means of a solar microscope, focused interference patterns of dif-

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9. Feb. 16, 1801, appointment to Royal Institution;
March 11, 1801, began duties;
June, 1801, appointed lecturer;
May 31, 1802, succeeded Garnett as Professor of Chemisty;
June 22, 1802, Wedgwood-Davy paper published in Journals Roy. Inst.; also, several papers on galvinism in Journals Roy. Inst. in 1802. See J. R. Partington, A History of Chemistry (London, 1964), Vol IV, p. 32.

10. Though the Journals had a limited circulation, the Wedgwood-Davy paper was reprinted in Nicholson's Journal of Natural Philosophy, Chemistry and the Arts, Nov., 1802. Sir David Brewster reviewed the experiments in the December, 1802, Edinburgh Magazine. Extensive discussion of the matter appeared in Frederick Accum, System of Theoretical and Practical Chemistry, 1803, and ~~in~~ John Imison, System of Theoretical and Practical Chemistry, 1803. See Gernsheim, p. 35.

ferent colored light onto a screen of paper which had been treated with silver nitrate, thereby temporarily recording the sizes of the interference patterns. He also reported, as did Wedgwood, that leather impregnated with silver chloride exceeds in sensitivity paper similarly treated.[11]

During the first two decades of the century Thomas Young, Augustin Fresnel (1788-1827), Etienne Malus (1775-1812), and Dominique Arago (1786-1853) created renewed interest in light theory by publishing treatises supporting and developing the newly revived wave theory of light. The gradual acceptance of the wave theory left photochemistry without a mechanistic explanation of light-matter interaction. Confronted also with the observed variation in actinic effect of different wave lengths of light, chemists and physicists such as Rumford, (1753), Berthollet (1748-1822), Gay-Lussac (1778-1850), Seebeck, (1780-1831), and Berzelius (1779-1848) turned to investigations of the nature of heat and light as well as of their effects on silver salts. In spite of these studies, during the first third of the century the idea of recording permanent, light-produced images apparently occurred to only a few and hardly at all to those with scientific training.[12]

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11. Thomas Young, "Experiments and Calculations relative to physical Optics," Philosophical Transactions of the Royal Society of London, LXXXXIV (1804), 15-16.

12. Florian Cajori, A History of Physics... (New York, 1962), pp. 148-156; Eder, Geschichte..., Vol. I, pp 158-226.

The discoveries of the elements iodine and bromine stimulated some investigations of their silver salts. Following Berhard Courtois's (1777-1838) discovery of iodine in 1811, Davy, while on tour in France in 1813, received a sample from André Ampère (1775-1836), tested it for many days, and made a report upon its elementary character to the Royal Society of London in 1814. While studying the compounds of iodine, he produced silver iodide and noted its sensitivity to light.[13] However, erroneous investigations by Steffins, Link, and Fischer contradicted Davy's observation of the light-sensitivity of silver iodide, and thereafter little attention focused on the matter until the late 1830's.[14] Meanwhile, in 1826 Antoine J. Balard (1802-1876) had isolated and recognized for the first time the elemental character of bromine. He had also reported that silver bromide darkens upon exposure to light but that it reacts more slowly to light than does silver chloride.[15]

On another front, progress in the isolation and

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13. Humphry Davy, "Some Experiments and Observations on a new Substance which becomes a violet coloured Gas by Heat," Phil. Trans. Roy. Soc. London, CIV (1814), 74-93. See especially page 76 for an account of his work with silver iodide.

14. Eder, Geschichte..., Vol. I, p. 210.

15. Antoine-Jérôme Balard, "Memoire sur une substance particuliere contenue dans l'eau de la mer," Annales de chimie et de physique, 2nd series, XXXII (1826), 337-381. See in particular pages 361-362.

understanding of certain organic substances used in tanning came at the end of the eighteenth century and during the first third of the nineteenth centuries. These organic substances later played an important role as photographic developers. About 1777 a committee of l'Académie de Dijon, which included de Morveau, Maret, and Durande, reported upon their extensive investigations of infusions of nut-galls.[16] Further development in the knowledge of tanning came about a decade later when Scheele presented an account of his investigations of what today are called gallic acid and pyrogallol.[17] Shortly after the turn of the century, Davy, upon the request of the managers of the Royal Institution, initiated studies of tanning chemistry and in 1802 and 1803 published two important papers on the subject.[18] Though studies of tanning chemistry continued during the first third of the century,

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16. "Sur le principe astringent végétal," in Appendice, Elémens de Chymie Theorique et Pratique (Dijon, 1778), facsimile reprint in Nierenstein, Incunabula..., pp. 12-30.

17. J. R. Partington, A History of Chemistry, (London, 1962), Vol. III, p. 233; Carl Wilhelm Scheele, "Über das wesentliche Gallapfelsalz...," Chemische Annalen (D.L.Crell), 1787, facsimile reprint in M. Nierenstein, Incunabula of Tannin Chemistry (London, 1932), pp. 37-42.

18. H. Davy, "Observations on Different Methods of obtaining Gallic Acid," Journals Roy. Inst., I (1801), (Reprinted in John Davy, Collected Works..., Vol. II and in Nierenstein, Incunabula..., pp. 65-68). "An Account of Some Experiments and Observations on the Constituent Parts of Some Astringent Vegetables; And on their Operation in Tanning," Phil. Trans. Roy. Soc. London, XCIII (1803). (Reprinted in Nierenstein, Incunabula..., pp. 116-157.)

the most important work, as far as photography is concerned, came in 1831 when Henri Braconnot (1781-1855) named pyrogallol and distinguished it from gallic acid. In addition, he reported that pyrogallol reduces silver nitrate to metallic silver much more rapidly than does gallic acid.[19] A few years later both gallic acid and pyrogallol began to play a significant part in the advancement of photographic technology.

Knowledge of solvents for silver chloride became widespread during the first third of the nineteenth century. The publications of Scheele, Berthollet (1748-1822), Faraday (1791-1867), and Liebig (1803-1873) made the solvent properties of ammonia generally known. In 1827 Gustav Wetzlar (1799-1861) indicated that a hot solution of common salt acts as a silver chloride solvent.[20]

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19. Henri Braconnot, "Experiences sur l'Acide gallique," *Ann. chim. phys.*, 2nd series, XLVI (1831), 206-211. See especially pp. 209-210 for the differing reducing effect of pyrogallol and gallic acid on silver nitrate. He noted that when gallic acid sat in air for a time it began to reduce the silver to the metallic state.

20. Carl Wilhelm Scheele, *Chemische Abhandlung*, pp. 65-69; Claude Berthollet, *Essai de statique chimique* (Paris, 1803), Vol. I, pp. 195-196; Michael Faraday, "On the Solution of Silver in Ammonia," *The Journal of Science and the Arts*, IV (1818), 268-273; Justus Liebig, "Verfahren, um Zeichnungen oder Flecken von sogennanter unverlöschlichen Dinte (salpetersaurem Silberoxyd) aus Zeugen zu bringen," *Annalen des Pharmacie*, V (1833), 290; Gustav Wetzlar, "Ueber eine Verbindung des Kochsalzes mit dem Hornsilber (chlorsilbersaures chlornatrium)," *Journal für Chemie und Physik in Verbindung mit mehren Gelehrten*, LI (1827), 371-374; see especially 371-372.

The most significant work contributing to knowledge of silver salt solvents appeared in a study of hyposulfurous acid by John Herschel in 1819. Shortly after graduation from Cambridge in 1816, the son of the famous English astronomer, Frederick William Herschel (1738-1822), had fallen under the influence of William Hyde Wollaston, who had interested him in chemistry. After considerable investigation, Herschel published a paper, "On the Hyposulphurous Acid and Its Compounds," in Brewster's Edinburgh Journal of Science.[21] Curiosity about a sulfur compound he had accidentally produced had prompted him to investigate the substance and consult Thomas Thomson's A System of Chemistry.[22] Several times in the paper Herschel emphasized that muriate of silver is soluble in alkali metal compounds of hyposulfurous acid, but most especially in sodium hyposulfite (sodium thiosulfate).[23] Soon Herschel's observations appeared in the popular textbook, A Manual of Chemistry (2nd ed., 1821), by Davy's successor at the Royal Institution, William Thomas Brande (1788-1866). Brande's text also noted that ammonia dissolved silver chloride.[24]

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21. John Herschel, "On the Hyposulphurous Acid and Its Compounds," Edinburgh Philosophical Journal, I (1819), 8-29 and 396.

22. Fourth edition, 1810, Vol. II, pp. 51-52; Fifth edition, 1817, Vol. II, pp. 112-113.

23. J. F. W. Herschel, Edinburgh Phil. J., I, 19 and 27.

24. Mention of sodium thiosulfate appeared in Vol. II, p. 270; this was also mentioned in the 1819 edition, pp. 312 and 314.

By the middle of the third decade of the nineteenth century, the knowledge required to implement a photographic process awaited integration and exploitation. The scientific community recognized the light sensitivity of the nitrate, chloride, iodide, and bromide of silver. It was argued that light reduced the salt to the metallic state, though the mechanism of the action was unknown. Discovery of the solvent properties of sodium thiosulfate made available immediately the fixing agent used most commonly throughout the 125-year history of photography. The papers of Wedgwood-Davy and Young carried the hint that leather somehow accelerates the action of light on silver salts. Thus, the soil in which the photographic process was to grow had been prepared. The seeds had been sown. In time, photographic processes could develop. However, the key element in the reduction of exposure time, namely, the latent image, still awaited discovery. Certainly, previous studies in chemistry in general and of silver salts in particular provided no hint that a catalytic reaction involving silver and certain reducing agents could be exploited for the recording of light-produced images. Thus, the fifteen years prior to 1839 represent a germination period during which several persons endeavored to achieve a practical photographic process. Early in 1839 these efforts became known.

Following this germination period, two different forms

of photography took root. In France the daguerreotype grew out of experiments with silver-iodide-coated copper plates on which positive camera obscura images were recorded, while in England the negative-positive form of photography emerged through the use of paper treated with light-sensitive silver salts. When exposed in the camera, such paper retained a negative impression from which positive prints could be secured. At first, the daguerreotype process eclipsed the English paper method, and it retained its popularity until the middle of the 1850's, but the obvious advantages of simple reproduction of positive prints soon brought the triumph of the negative-positive method, though glass replaced paper as the base because of its superior properties of transparency.

The daguerreotype process grew out of experiments conducted over a twenty-five year period by Joseph Nicéphore Niepce (1765-1833) and Louis Jacques Mandé Daguerre (1787-1851). Niepce, born of wealthy parents in Chalon-sur-Saône, was educated at a Roman Catholic seminary. Because of the Royalist sympathies of his father, the family felt compelled to leave its home during the French Revolution; yet, Niepce later returned to Chalon-sur-Saône, where, because of his independent means, he enjoyed much free time for mechanical and chemical experiments. At the time of the restoration of the monarchy in 1814, the relatively new process of

lithography enjoyed popular attention in France and soon engaged the attention and interest of Niepce. While pursuing his efforts to produce images and outlines directly upon lithographic stones, Niepce sought also to record camera obscura images. During the spring and early summer of 1816, he captured such images on silver chloride and endeavored to fix them with nitric acid. Unable to fix these images permanently, he abandoned the silver salts and for the next ten years tested a variety of other light-sensitive substances, including guaiacum and asphaltum. Though he lacked a formal scientific education, Niepce consulted Klaproth's Dictionnaire de Chimie and perhaps sought other scientific references. By the middle of the 1820's, Niepce's persistence had yielded a method of producing permanently-fixed camera obscura images on bitumen of Judea, but the process required an eight-hour exposure period.

During the next few years he continued his experiments in an effort to reduce the required exposure time. Niepce improved his process by placing the light-sensitive bitumen on silver-coated copper plates. In the camera the bitumen exposed to sunlight hardened while the unexposed areas remained soluble in oil of lavender and white petroleum. After removing the soluble bitumen, Niepce placed the plate in an enclosed box with iodine vapors. These vapors acted chemically upon the silver bared by

the removal of the bitumen and produced dark silver iodide. Then, after removing the plate from the iodine box, he dissolved the hardened bitumen in alcohol, thereby making a positive picture with silver producing the high lights and the silver iodide producing the shadows.[25] Daguerre, an artist with little schooling, had become an apprentice to an architect at an early age. Later he had studied painting under Degotti at the Paris Opera and at that time had revealed a talent for producing scenery. In the 1820's he had exploited this talent by designing sets which captured the attention of Paris because of their unusual realism. Daguerre's clever use of paintings, lighting effects, and properties permitted eager Parisians, tired of the drabness of the city and perhaps influenced by the sentimentality characteristic of the Romantic Movement, to have luncheon "in the Swiss Alps" or in some pastoral setting at what Daguerre called the diorama. Daguerre's concern for realism and reproduction of scenery stimulated his interest in efforts to record camera images.[26]

The hope of gaining new knowledge from each other

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25. Eder, History..., pp. 193-197; Gernsheim, pp. 36-40; Rene Colson, *Mémoires originaux des créaturs de la photographie* (Paris, 1898), pp. 13-43.

26. Eder, *History*..., pp. 209-257; Gernsheim, pp. 48-60; Helmut and Alison Gernsheim, *Louis M. J. Daguerre* (New York, 1959), pp. 100-105; Beaumont Newhall, *On Photography, A Sourcebook of Photo History in Facsimile* (Watkins Glen, N. Y., 1956), pp. 24-48; Colson, pp. 44-70.

brought these two relatively untrained experimenters, Daguerre and Niepce, together in a legal partnership, a joint endeavor to produce a practical photographic process. In this partnership Daguerre benefitted the most. Niepce learned of an optical improvement for his camera, but Daguerre learned how to produce permanent pictures, something he had not known previously. Both continued to work separately but to share ideas and make suggestions.

In spite of Niepce's original superiority in knowledge and success in recording permanent pictures, it was Daguerre who in 1831 made what was probably one of the most important discoveries in the history of photography, namely, that of the latent image. This fortuitous discovery came a few days after he had placed some under-exposed silver iodide plates in a reagent cupboard. Upon returning to the cupboard, he found the plates had imprinted upon them the images to which they had been exposed earlier. After puzzling over this remarkable event, he repeated the process, placing an under-exposed plate in the cupboard; and again he found complete pictures. To discover the chemical cause in his "magic cupboard," Daguerre repeated this procedure while each day removing another reagent from his cupboard, until he finally found that mercury from a broken thermomenter had caused the development of the latent image. Thus, Daguerre

had possession of a new process which he called the daguerreotype. He first sensitized silver-coated copper plates with iodine vapors just prior to exposure in a camera. Then, after their exposure to light, he developed the latent image by treating the plate with mercury vapors. His discovery of the latent image and use of it in his new process reduced the exposure time from hours to minutes.

Following the death of Niepce in 1833, Daguerre continued his experiments; however, the problem of a fixing agent again became a stumbling block. By 1837 Daguerre had either learned or discovered that warm sodium chloride solution would at least partially fix his daguerreotypes. Soon Daguerre's attention focused upon the exploitation of the new process. He and Niepce's son, who held a revised partnership agreement with Daguerre, sought to sell stock in a company formed to commercialize the process, but these efforts did not meet with the expected success.[27]

In 1838 Daguerre tried another approach, bringing his process to the attention of certain leading scientists then living in France, including Arago, Biot, and Humboldt. Arago recognized the great potential of this discovery for science and, as a member of the Chamber of Deputies, enlisted the support of its members and encouraged

27. Ibid.

Guy-Lussac, a member of the Chamber of Peers, to induce the Chamber of Peers to support a pension for Daguerre and Niepce. In return, they were to free the process for general use. By early August, 1839, the French government had formally approved the pensions and "donated the process to the world."[28] On August 19, 1839, Arago described in detail and demonstrated the process before an overflow crowd at a special meeting of l'Académie des Sciences and l'Académie des Beaux-arts in Paris. The public response to the August demonstration was very enthusiastic, and immediately there was an overwhelming demand for cameras, chemicals, and auxiliary equipment.

The introduction of photography on paper depended in large part on the activities of three Englishmen, namely, the Reverend Joseph Bancroft Reade (1801-1870), William Henry Fox Talbot (1800-1877), and Sir John Herschel. These three possessed better scientific educations and ~~had stronger links with prominent scientists and scientific~~ institutions than Daguerre and Niepce. John Herschel, of course, was one of the leaders of English science in this period, while Talbot and Reade, though not leaders,

28. The French government made a big point that they were donating the photographic process to the world, but Daguerre took out a patent on the process in England through an agent and continued throughout the 1840's to enforce this patent. Of course, the English resented the French "donation."

were active in British scientific circles.

Reverend Joseph B. Reade, trained as a clergyman and active as a rector throughout his life, demonstrated an early and enduring interest in chemistry, microscopy, and astronomy. Elected as a fellow of the Royal Society of London and th Royal Astronomical Society, he assisted in founding the Royal Microscopical Society and later accepted the chair of President. While carrying out a large number of microscopical studies, he found his lack of artistic ability a handicap and therefore hired a friend to do copying for him. Because of the expense of such a procedure, he sought a cheaper mechanical method of recording observations. In early 1837, after he had read the papers of Young, Wedgwood, and Davy, he sought to record solar microscope images on leather sensitized with silver chloride or silver nitrate.[29] Reade's wife, however, objected to his continued use of her white ~~leather gloves; therefore, he decided to tan paper,~~ guessing correctly that something in the tanning process increased the sensitivity. At first when he tried tanning the paper, the entire surface of the resulting picture quickly turned to metallic silver because the solution was too concentrated; however, the fleeting glimpse of the image prior to complete blackening encouraged Reade to

29. A solar microscope was the equivalent of a modern opaque projector.

dilute his solution until reaching a desired level of discriminate reduction. He did not, however, discover the latent image and gallic acid development but simply applied the solution rich in gallic acid to the paper prior to exposure. Shortly thereafter, he successfully used the gallic acid as an accelerator on paper impregnated with silver iodide. Reade later mentioned that he had learned of the light sensitivity of silver iodide from Davy's paper of 1814.[30]

Reade was troubled, as were all early photographic investigators, by the fixing agent problem. While searching for a suitable solvent, he turned to Brande's Manual of Chemistry; and finding hyposulfite of soda (sodium thiosulfate) recommended as a silver chloride solvent on the authority of John Herschel, he used this substance with marked success.[31] Thus Reade attained the objective which Davy had set for himself some thirty-five ~~years earlier. It is striking how successfully Reade~~ synthesized certain photochemical knowledge of the previous third of a century, building upon the published work of Wedgwood, Young, Davy, and Herschel (by way of Brande). Unfortunately, Reade failed to publish or communicate his photographic investigations to his

30. See Reade's letter reprinted in John Werge, The Evolution of Photography (London, 1890), pp. 15-21; "Joseph Bancrot Reade," Dictionary of National Biography, Vol. 16, 803-804.

31. Ibid.

scientific associates. Though he told a few friends of his work, it was not until after the announcements of Talbot and Herschel that his studies came to light, and even then he did not seek attention or priority for himself. As we shall see later, Reade did, however exert some influence on Talbot, and this influence played an important role in Talbot's discovery of the latent image and organic developers.

William Henry Fox Talbot, the son of a landed English family, received a good education at Trinity College, Cambridge, and graduated twelfth wrangler in 1821. Early in life his interests lay in mathematics, optics, and photochemistry but later turned to archeology and linguistics. In 1831 his work in mathematics brought him election as a fellow of the Royal Society. Early in 1834 he began his efforts to record light images such as those obtained with a camera lucida. By 1835 he had employed solutions of silver nitrate and dilute sodium chloride to make the sensitive surface on paper; and after unsuccessfully trying ammonia and potassium iodide as fixing agents, he began using a sodium chloride solution; but his fixed pictures consisted only of contact prints. In order to employ a camera, he had to reduce the exposure time. By using alternating layers of sodium chloride and silver nitrate on the paper, by employing very small cameras with very short focal lengths, and by

exposing the sensitive paper while it remained moist, he obtained a camera picture in the summer of 1835 with an exposure of only thirty minutes. Later, he also employed the solar microscope. Like Reade, Talbot continued to pursue these experiments but did not bring them to public attention.[32] When Arago announced to the Academy of Sciences on January 7, 1839,[33] that Daguerre possessed a process for mechanically producing pictures, Talbot immediately initiated efforts to make his work public. He exhibited some of his photographic drawings at the Royal Institution on January 25th, sent letters on January 29th to Arago and Biot in which he claimed priority in the use of the camera and the fixing of pictures, and announced to the Royal Society on January 31st that he had obtained a successful photographic process.[34]

Meanwhile, Captain Beaufort, a close friend of Herschel, had heard of Daguerre's work and, in a note which Herschel received on January 22nd, drew his attention to the new process. Soon Herschel set to work to try to duplicate the results of Daguerre, though he knew no

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32. Newhall, pp. 60-74; Eder, History..., pp. 316-330; Gernsheim, History..., pp. 61-68; and W. H. F. Talbot, "Some Account of the Art of Photogenic Drawing...," Proc. Roy. Soc. London, IV (1839), 120-121.

33. Dominique F. J. Arago, "Fixation des images qui se forment au foyer d'une chambre obscure," Comptes rendus hebdomadaires des séances de l'Académie des Sciences, VIII (1839), 4-7.

34. Ibid., VIII, 170-171; W. H. F. Talbot, Proc. Roy. Soc. London, IV, 120-121.

details of the Frenchman's methods.[35] By January 29th his work had progressed to the point where he was using the carbonate, acetate, nitrate, and chloride of silver to coat high-quality paper. He used sodium thiosulfate as his fixing agent on this day and later remarked that in these early experiments he "never used anything else."[36] This is not surprising in view of his earlier study of the hyposulfurous compounds and their properties. On the following day he obtained his first successful photograph, fixing a camera obscura view of the forty-foot telescope at Slough.[37] On the same day, having learned of Talbot's interest and work in photography, perhaps from his exhibit at the Royal Institution, Herschel drafted a letter to Talbot.[38] On the 31st Talbot presented a paper to The Royal Society in which he described his methods but provided no details as to the chemicals used.[39] On the

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35. J. F. W. Herschel, "Note on the Art of Photography..," _Proc. Roy. Soc. London_, IV (1839), 131.

36. "... and it was not a _suggestion_, but a regular and uniform _practice_, to use the hyposulfite; I never used anything else." Letter of John Herschel dated October 29, 1864, reprinted in _British Journal of Photography_, XXXIV (1887), 372-373. The details of his experiments on January 29th are from: "Photographic Notebook;" photographic reprint in _Photographische Korrespondenz_, CI (1964), 46.

37. _Ibid_.

38. J. F. W. Herschel, "Diary, 1839," (unpublished manuscript in the Herschel Collection in the Miriam Lutcher Stark Library, University of Texas), entry for January 30th.

39. W. H. F. Talbot, _Proc. Roy. Soc. London_, IV, 120-121.

following day when Talbot visited Herschel at Slough, Herschel described fully his process to Talbot, including the use of sodium thiosulfate as a fixing agent.[40] Thus this important piece of information was in Talbot's hands by the first of February.

During the next month and a half photography was the subject of a number of letters between scientists in England and France, and some of these letters were concerned with Herschel's new fixing agent. Talbot was in close touch with Arago and Biot, Daguerre's scientific mentors, writing letters on January 29th, February 20th, and March 1st in which he claimed priority in fixing camera obscura images but provided little useful information about his process. Biot, in turn, responded to these communications, trying to elicit further information about Talbot's process. In a letter written to Talbot February 12th and 13th, Herschel indicated that he had found that, in addition to sodium thiosulfate, which Talbot already knew about, potassium ferrocynate was a fixing agent for silver salts.[41] When Talbot wrote to Biot on the 20th and 21st, he indicated that Herschel had a new fixing agent but offered no details. However, in the letter of March 1st to Biot, Talbot indicated that

40. J. F. W. Herschel, Photog. Korresp., CI, 46.

41. J. F. W. Herschel, [Letter to W. H. F. Talbot, Slough, February 12, 1839], typescript copy in manuscript collection of Miriam Lutcher Stark Library, University of Texas.

the two fixing agents introduced by Herschel were sodium thiosulfate and potassium ferrocynate.[42] This letter was read to l'Académie des Sciences on March 4th and published in Comptes rendus.[43] Ten days later Herschel himself described his process for a meeting of the Royal Society.[44] Within a short time, no doubt through the influence of Biot, Arago, or some other member of l'Académie des Sciences, Daguerre learned of sodium thiosulfate and included this efficient fixing agent in the first description of his process published in the summer of 1839.[45]

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42. W. H. F. Talbot, [Letter to Biot, London, March 1, 1839], Compt. rend., VIII (1839), 341-342. Eder and Gernsheim credit Talbot with the discovery of potassium ferrocynate as a fixing agent, but Talbot's letter makes clear that both substances, namely, potassium ferrocynate and sodium thiosulfate, were first used as fixing agents by Herschel. "...je vais indiquer une troisième et quatrième méthode, dont la découverte est due à mon ami sir John Herschel qui m'a écrit qu'il permet volontiers leur publication.

"La troisième méthode pour fixer un dessin photogenique, consiste à le laver avec le ferro-cyanate de potasse. . .

"La quatrième méthode, et qui vaut à elle seule toutes les autres ensemble, c'est de laver le dessin avec l'hyposulfite de soude. Ce procédé a dû se présenter tout naturellement à l'esprit de M. Herschel, puisqu'il a lui-même découvert l'acide hyposulfureux. . ."

43. W. H. F. Talbot: [Letter to Arago, London, January 29, 1839], Comptes rendus, VIII (1839), 170-171; [Letter to Biot, London, February 20 and 21, 1839], Ibid. VIII, 302-305; [Letter to Biot, London, March 1, 1839], Ibid., VIII, 341-342.

44. J. F. W. Herschel, Proc. Roy. Soc. London, IV, 131.

45. The first edition of Daguerre's manual, Historique et description des procédés du Daguerréotype et du Diorama (Paris, 1839), is very rare; therefore, I have consulted the text reprinted by Colson, p. 60, and the 1839 English reprint published in facsimile by Newhall, p. 35.

Thus, the sequence of events from the 1819 discovery of the solvent properties of alkali thiosulfate (hyposulfurous) compounds for silver chloride to the introduction of sodium thiosulfate in Daguerre's process in 1839 reveals the close interplay of scientists and scientific societies in this particular advance in photographic technology. Although Herschel's study of the thiosulfates was reported in leading chemistry textbooks such as that of Brande, this information was slow in reaching those working with photography. However, Herschel's initial interest in photography combined with his general knowledge of chemistry and specific knowledge of the silver chloride solvent brought the use of sodium thiosulfate into photography at a relatively early date.

Talbot, who was anxious to obtain recognition for his work in photography, was in close communications with Arago and Biot; and because of this close association, the three men acted as the intermediaries between Herschel and Daguerre. Both the Royal Society and l'Académie des Sciences played important roles in stimulating personal communications and dispersing technical information.

Throughout 1839 and early 1840 Herschel continued his investigation of photography and turned to its use in spectrum studies. After presenting his first paper on the subject to the Royal Society on March 14, 1839, he prevented

its publication.[46] On February 20, 1840, he read another paper, in which he summarized his investigations and findings from January 22, 1839. In this paper he reviewed a number of fixing agents but recommended most highly sodium thiosulfate. Then his attention turned to the chemical effects of the solar spectrum. He made efforts to record the Fraunhofer dark lines but could not produce convincing evidence of such lines in the "chemical spectrum." Subsequent papers by Herschel on spectrum characteristics indicate that his work in photography stimulated his interest in spectrum studies.[47]

Meanwhile, Reade's work had come to light and stimulated further investigations by Talbot. In April, 1839, Reade and Talbot both exhibited their photographic works at Lord Northhampton's estate.[48] Soon Talbot learned of Reade's use of gallic acid and began photographic experiments using gallic acid as an accelerator. One day in September, 1840, Talbot exposed some photographic paper, and it failed to produce a visible image; accordingly, he decided to use the paper over again and, therefore, started to sensitize it again with gallic acid and silver nitrate, whereupon the gallic acid developed the

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46. J. F. W. Herschel, "Note on the Art of Photography...," Proc. Roy. Soc. London, IV (1839), 131-132.

47. J. F. W. Herschel, "On the Chemical Action of the Rays of the Solar Spectrum... and on Some Photographic Processes," Phil. Trans. Roy. Soc. London, CXXX (1840), 1-59.

48. See Reade's letter reprinted in Werge, p. 18.

latent image, markedly decreasing the required exposure time for photography on paper. By June, 1841, the new advancement had become generally known.[49] Thus, we can trace the circuitous route of idea transfer from Wedgwood and Davy's first hint of the accelerating effect of leather to Reade's recognition of gallic acid as the accelerating substance and, finally, to Talbot's fortuitous discovery of the latent image.

After the successful introduction of the daguerreotype and paper processes in 1839, commercial photographers began experimenting with these processes and soon reduced the required exposure time. John F. Goddard (c. 1795-1866), a science lecturer at the Adelaide Gallery in London, reported late in 1840 that he had made daguerreotypes more sensitive by exposing them to a combination of iodine and bromine vapors instead of to iodine vapors alone. Six months later another English photographer, Antoine Claudet (1797-1867), reported to the Royal Society of London that daguerreotypes prepared with combinations of iodine and chlorine or iodine and bromine possessed increased sensitivity. About the same time a German, Franz Kratochivila, demonstrated to Liebig and Wohler the improved sensitizing characteristics of combined chlorine and bromine vapors.

49. W. H. F. Talbot, "An Account of Some Recent Improvements in Photography," Proc. Roy. Soc. London, IV (1841), 312-315.

These discoveries reduced the exposure time for a daguerreotype from several minutes to a few seconds.[50]

Advances were also made in the paper photographic process. In 1844 the Frenchman, Louis-Désiré Blanquart-Evrard (1802-1872), explained to l'Académie des Sciences in Paris that when, instead of coating the surface of paper with the sensitive materials, he had floated the paper on successive baths of iodide salt and silver nitrate, the paper had become thoroughly impregnated with silver iodide, thereby producing improved tone and detail. Furthermore, he noted that if the treated paper was again moistened with an acid solution of silver nitrate, the sensitivity was increased fourfold over that of Talbot's calotype or the daguerreotype.[51]

From the earliest days of photography, attention also focused upon improving and understanding the fixing process. In 1840 a French physicist, Armand Hippolyte Louis Fizeau (1819-1896), employed gold chloride in the fixing bath for daguerreotypes.[52] This gold solution improved the tone, decreased the glare, and aided in extending the life of daguerreotypes. Later in the decade

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50. Eder, History..., pp. 275-278. He draws from contemporary German newspaper sources. See Antoine Claudet, "New Mode of Preparation of the Daguerreotype Plates...," Proc. Roy. Soc. London, IV (1841), 315-316.

51. Gernsheim, History..., p. 143.

52. Armand H. L. Fizeau, "Fixation des images photogeniques sur métal," Compt. rend., X (1840), 488.

photographers began also to tone silver prints with gold. From the first, chemists were interested in the fixing process. In 1841 A. Lenz, a German chemist, argued that sodium thiosulfate formed water soluble double salts with the silver nitrate. After analysis of these salts, he concluded that they were $Ag_2S_2O_3 \cdot Na_2S_2O_3$ and $Ag_2S_2O_3 \cdot 2NaS_2O_3$.[53] Even though the state of chemical analysis at the time was not very sophisticated, it will be seen that these formulas continued to be cited in the photographic literature throughout the remainder of the century.[54]

In the early 1840's improvements in the daguerreotype made good portrait and landscape photography possible. In France, in the United States, and somewhat less in Germany, the daguerreotype process captured much public attention and soon became very popular. In England, however, commercial photography by means of either the calotype or daguerreotype process remained in a comparatively embryonic stage, perhaps because of the patent and licensing limitations imposed there by both Talbot and Daguerre.[55] Though a few individuals in England profited handsomely from photography in the 1840's, it was not until

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53. A. Lenz, "Analyse einige Doppelsalze der unterschwefligen Säure," Annalen der Chemie und Pharmacie, XL (1841), 98.

54. See footnote number 84.

55. The daguerreotype was patented only in Great Britain. The calotype process was patented in the United States and Great Britain, but the patents were not renewed in the 1850's when they came up for renewal.

the character of the photographic process changed in the 1850's and the patent barriers were lifted that the photographic art became a vigorous commercial enterprise in England.

The late 1840's ushered in an era of significant change in photographic technology with the introduction of photography-on-glass and the discovery of collodion. The first step in the change in photographic technology was the adoption of glass negatives in photography. Though John Herschel used glass plates as early as 1839, early photographers did not readily adopt this support. Several years later Abel Niepce de Saint-Victor, a cousin of Nicéphore Niepce, reintroduced and successfully popularized glass photographic plates. First Niepce had tested starch paste, syrup, gelatin, and albumen as binding materials to hold the sensitive silver salts to the glass. In October of 1847 he reported to l'Académie des Sciences in Paris that he had succeeded in using albumen as a binder for the silver iodide sensitive salt. In this albumen process he also employed gallic acid as the developer.[56] Soon the albumen process became popular, and the demand for egg whites, the source of albumen, soared. In England, however, Talbot's patents discouraged acceptance of the process.[57] By the time Talbot lifted this restriction,

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56. Abel Niepce de Saint-Victor, "Note sur la photographie sur verre," *Compt. rend.*, XXVI (1848), 637-639.

57. See Gernsheim's discussion: *History*.., p. 149.

a new process had replaced it.

The second step in the change in photographic technology followed the discovery of guncotton and collodion in the late 1840's. Christian Friedrich Schönbein (1799-1868), a German-Swiss professor of chemistry and physics at the University of Basel, observed that nitric acid transforms cotton into an explosive substance which he named guncotton (trinitrated cellulose). Schönbein announced his discovery in March of 1846. Immediately he conveyed this information to Faraday in England and to Dumas in Paris. Dumas made Schönbein's letter known to l'Académie des Sciences in Paris in the early fall of 1846. During 1846 the German chemist, Rudolph Christian Böttger (1806-1881), also independently produced guncotton. Soon Schönbein and Böttger collaborated in their studies of this substance. Many chemists began repeating and investigating Schönbein's work.[58] Shortly thereafter, treatment of cellulose with a mixture of sulfuric and nitric acid became the common method of production of guncotton.

In 1847 the Frenchmen Flores Domonte and Louis Ménard discovered that certain kinds of nitrocellulose are soluble

58. Partington, IV, 190, 195, and 196; see also Christian F. Schönbein, "Ueber Schiesswolle, deren chemische Zusammensetzung und Eigenschaften, verglichen mit denen des Braconnot 'schen Xyloidins," Annalen der Physik und Chemie, LXX (1847), 320-326.

in organic solvents.[59] In spite of the difficulties in making accurate chemical analyses at that time, Domonte and Ménard recognized that the insoluble guncotton possessed a higher nitrogen content than soluble cellulose nitrate. However, their study did not yield a useful formula for collodion, as the soluble cellulose nitrate became known.[60] The exact structure and composition of cellulose and its derivatives remained unknown in the nineteenth century.[61] Yet the general properties of collodion, especially its adhesive quality, were quickly recognized by its discoverers in the late 1840's, and soon physicians adopted it for use in skin treatments and surgery.

Shortly after the discovery of guncotton and collodion, photographers adopted collodion as a binding medium for sensitive photographic salts. In the fall of 1848 an Englishman, Frederick Scott Archer (1813-1857), initiated experiments in which he placed collodion on paper.[62] In June of 1849 Archer coated glass plates with a collodion emulsion containing potassium iodide and then washed the

59. Maynard and Bégelow in the United States also did early independent work with collodion.

60. Eder, History..., pp. 342-343; see also Compt. rend., XXIII (1846), 1087; XXIV (1847), 87 and 390.

61. The general structure of this polysaccaride became known in the twentieth century following Emil Fischer's work on the structure of sugars late in the nineteenth century.

62. Werge had Archer's negatives in his possession. See Werge, pp. 66-67.

coated plates with silver nitrate just prior to exposure. He published the results of his experiments in the March, 1851, issue of The Chemist. During the summer of 1850 Gustave Le Gray (1820-1882), a French painter and photographer, began employing collodion in his photographic work. He made vague references to a collodion photographic process in a pamphlet which he published in 1850, Traité pratique de photographie sur papier et sur verre.[63] It remained, however, for Archer's published announcement to initiate the movement to collodion-on-glass photography, which became the dominant photographic process from the mid-1850's until the ascendancy of the gelatin process about 1880.

The wet collodion process came to replace the daguerreotype and calotype processes because of certain technical advantages, but the complications of the process limited its use of professionals and to only the most enthusiastic and patient amateurs. The photographer had to coat the glass plates with iodized collodion and then dip them in a silver nitrate bath just prior to exposure. Therefore, the photographer had to carry with him, in addition to his tripod and camera, a cabinet of chemicals and a tent or portable darkroom for preparation of the sensitive plates. Development generally took place

63. Eder, History..., pp. 344-346; Gernsheim, History..., pp. 152-153.

shortly after exposure of the plates. In spite of these inconveniences, photographers recognized the superiority of the wet collodion process[64] over earlier processes, especially with respect to sensitivity and fineness of detail. Furthermore, the photographer could easily produce multiple prints, an advantage over the daguerreotype. While the calotype allowed the photographer to produce prints, the improved transparency of glass gave advantage over this paper process.

At the same time that photographic technology was changing during the late 1840's and early 1850's, especially with regard to the carrier and the adhering substance, changes came in methods of development. Photographers developed the daguerreotype with mercury vapors and the calotype with gallic acid and silver nitrate. In the development of calotype negatives, the gallic acid acted as a reducing agent in what was known as physical development. In 1844, however, Robert Hunt (1807-1887) introduced a new developer, iron sulfate. Hunt, a professor of mechanical engineering at the Royal School of Mines in London, had conducted many photographic and photochemical experiments from the time of the earliest announcements of a photographic process in 1839. When

64. Called the wet collodion process because the exposure was taken immediately after the silver nitrate had been applied; hence, the plates were still wet.

Niepce de Saint-Victor introduced his albumen process, he retained Talbot's gallic acid developer, but soon others began to employ iron sulfate in this process.[65]

At mid-century two leading scientists discovered the developing properties of pyrogallol. In 1831 Henri Braconnot, while working with pyrogallol, had noted that it reduces silver nitrate to silver much more rapidly than gallic acid does, but this observation was of no importance to a field still unborn at the time.[66] Twenty years later, however, this property became significant to photography. Typical of many scientists of the day, Justus Liebig (1803-1873), the famous German chemist at Giessen, and Henri V. Regnault (1810-1878), a physicist and chemist at College de France, took photographs and experimented with the process itself. In 1851 both of these scientists independently discovered the superior developing properties of pyrogallol. When Regnault exhibited photographs in early 1851 at the Société Héliographique in Paris, their good middle tones drew favorable attention and the disclosure of his new developer.[67] Pyrogallol became an important developing agent in the waning calotype and albumen processes as well as in the new wet collodion procedure. Archer may have used pyrogallol as a developing

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65. Robert Hunt, "On the influence of Iodine...," Proc. Roy. Soc. London, IV (1840), 239.

66. Braconnot, Ann. chim. phys., XLVI, 206.

67. Eder, History..., p. 330; Humphrey's Journal, IV (1852), 49, (reprint from Le Technologiste).

agent from the first in his wet collodion process, but the first published mention of his method came in 1851.[68] Eventually iron sulfate partially replaced pyrogallol as a developer in the wet collodion process, but the latter continued to be used as an intensifier and again regained importance as a developer with the introduction of gelatin plates later in the century.

At the time of the change to collodion photography, some of the early investigators tried to employ gelatin as a binding agent, but these efforts met with failure. Niepce de Saint-Victor unsuccessfully sought to use a gelatin emulsion in the late 1840's.[69] At mid-century a Frenchman, Alphonse Louis Poitevin (1819-1882), conducted experiments with gelatin,[70] but the deleterious effects of silver iodide and gallic acid on gelatin hindered successful employment of it in photography at this time. Therefore, in the 1850's photographers ~~failed to recognize the importance of gelatin as a binder.~~ It remained for the next generation to seize upon gelatin and exploit its properties for use in photography.

After a decade of successful use of the wet collodion process, some significant observations brought further

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68. Werge, p. 42, from Frederick Scott Archer, "On the Use of Collodion in Photography," The Chemist, new series, II, (March, 1851).

69. Abel Niepce de Saint-Victor, Compt. rend., XXVI (1848), 637-639.

70. Alphonse Louis Poitevin, "Photographie sur gélatine...," Compt. rend., XXXIII (1850), 647-650.

advances in photographic technology. In 1861 James Mudd, an Englishman, announced that he and his assistant, Wardley, had observed that aqueous "pyrogallic acid" alone could satisfactorily develop wet plates, thereby eliminating the need for the costly silver nitrate in the developing solution.[71] This process was known as chemical development, as contrasted to physical development, which required silver nitrate in addition to a suitable reducing agent. About the same time the important New York photographic manufacturer and dealer, Henry T. Anthony, noted that exposure of photographic plates to ammonia fumes increased their sensitivity. When, in September of 1862, Major C. Russell (1820-1887) in England learned of Anthony's observation, he substituted ammonia for the usual acetic acid in the pyrogallol developing solution and found the combination an effective and more energetic developing solution than acid pyrogallol. Others, including Glover and Leahy, also observed that alkaline pyrogallol exceeded either acidic pyrogallol or gallic acid in developing effectiveness.[72]

During the 1860's a number of different photographic processes were introduced, but none was of lasting significance. Amateurs and even some manufacturers prepared dry collodion plates. Though photographers used them under special circumstances, such plates suffered from lack of

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71. Eder, History..., p. 375.
72. Brit. J. Photog., XVIII (1871), 265.

sensitivity, greatly reducing their usefulness and popularity. The ferrotype or tintype became popular in the late 1850's and early 1860's. It consisted of direct positives on flexible galvanized iron or tinned plates. This process temporarily captured the trade in the United States, primarily because of its cheapness, but met with its greatest popularity in Europe in the late 1870's, when street photographers promoted sale of tintypes, especially in England.[73]

With the advent of glass-negative processes and especially the collodion process, positive printing papers became important in photography. From early in the 1850's albumen-coated paper held an important place in the trade. The albumen, obtained from egg whites, contained a halide salt, generally sodium chloride. Just prior to the time of printing, the photographer sensitized the albumen paper by washing it in a silver nitrate bath. Printing required long periods of exposure to sunlight. The light reduced the sensitive silver halide directly to metallic silver, without the need for development. After printing, the photographer fixed the print with sodium thiosulfate. Albumen paper remained the principal printing paper until the time of introduction of gelatin into photographic

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73. Compare the accounts of the history of tintypes in the United States, England, and the Continent in the following: Robert Taft, Photography and the American Scene (New York, 1964), pp. 153-166; Gernsheim, History..., pp. 168-170; and Eder, History..., pp. 369-370.

technology during the last two decades of the century.

Thus, from 1850 to 1880 the wet collodion-on-glass process dominated photography. Since the wet collodion process exceeded the daguerreotype and calotype processes in sensitivity, the required exposure time was substantially less. The collodion negatives and albumen prints also represented an improvement in fineness of detail and in duplicability of photographs. It remained, however, for later chemical advances in photographic technology to usher in the era of instantaneous photography, when the photographic process became more fully exploited by amateur, professional, artist, and scientist alike.

The second great technological revolution in photography began in England in the early 1870's with the successful introduction of gelatin emulsions; but several investigators, as indicated earlier, had unsuccessfully sought to employ gelatin in the photographic process from the time of the introduction of collodion. In addition to the efforts of Niepce de Saint-Victor and Poitevin, Tavistock, an English amateur photographer, had reported in 1854 substituting gelatin for collodion or albumen. In 1861 Alexis Gaudin, the editor of the French photographic journal, La Lumière, had described his use of a silver-iodide gelatin emulsion, but he had further noted that the process required an exposure time equal to that of the slow albumen plates. Thomas Sutton of Jersey had suggested

that the Gaudin process could be improved by using the bromide rather than the iodide of silver, but he had failed to provide experimental confirmation for his suggestion. Therefore, in spite of the availability of gelatin as a binder or vehicle for a photographic emulsion from the late 1840's, certain inherent difficulties had apparently retarded the successful introduction of this important substance in photography. The common use of potassium iodide and gallic acid in the preparation and development of photographs had hindered the successful application of gelatin to the then current photographic processes.[74]

Successful use of gelatin in photography depended then upon the use of an alternative silver halide, namely, silver bromide, as the major sensitive salt and the use of alkaline chemical development. An Englishman, W. H. Harrison, met with partial success in 1868, using gelatin emulsion of silver bromide and iodide which, after exposure, he developed with pyrogallol. Such an effort created interest at the time because Harrison exposed the plates while they were dry; however, the surface of the dry emulsion became rough. Further efforts by Harrison to avoid the surface problems failed. Apparently Harrison's results did not encourage other experimenters to use

74. Both the iodide and the gallic acid reacted with gelatin, destroying its hard texture.

silver bromide gelatin emulsions in photography during the next few years. It remained, therefore, for an English physician and amateur photographer, Richard L. Maddox (1816-1902), to report first the successful use of a gelatin silver bromide emulsion. In a paper appearing in The British Journal of Photography in September of 1871, Maddox described his process. Basically, he substituted gelatin for collodion, producing an emulsion of silver bromide in gelatin. After the plates had dried, he exposed them for one-half to one-and-a-half minutes. Then he developed the negatives with acidic pyrogallol, followed by another bath of pyrogallol and some silver nitrate. Hence Maddox did not break completely with physical development in this effort. Finally, he fixed the plates with sodium thiosulfate. In addition to executing this process on glass, Maddox also employed this process on a paper base. He pointed out that many further experiments should be pursued and suggested trying iron sulfate, gallic acid, and lead acetate developers. He indicated, however, that such trials would have to be done by others since he could no longer pursue these experiments because of his health.[75]

75. W. H. Harrison, "The Philosophy of Dry Plates," Brit. J. Photog., XV (1868), 44; R.L. Maddox, "An Experiment with Gelatino-bromide," Ibid., XVIII (1871), 422-423: biography of Maddox: Ibid., XLVII (1902), 425-427.

Soon improvements in the new gelatin process followed, but professional photographers adopted the new process only very slowly. In the summer of 1873 Burgess in England advertised gelatin dry plates for sale, and soon Joseph Swan (1828-1914) added gelatin dry plates to his production of collodion dry plates.[76] Yet as John Werge, an agent for Kennett dry plates after 1874, described, few professionals even tried gelatin dry plates at first.[77] Part of this reluctance may have been due to the increased sensitivity of the new plates and, accordingly, the great care required in handling and processing them. Amateurs, however, were less conservative and more readily adopted the new products. Yet by the late 1870's even the professional photographers in England had begun to accept the gelatin plates. In the early 1880's the production of gelatin plates spread to Germany, France, Belgium, and the United States. The general availability of plates superior to the old wet and dry collodion plates in the retention of their sensitivity, the shortness of required exposure, and the simplicity of development prompted the general acceptance of gelatin dry plates by both professional and amateur alike. Furthermore, with the simpli-

76. For a discussion of Burgess's work see Gernsheim, History..., pp. 263-264; Richard Kennett also began manufacture of gelatin plates about March of 1876. Swan began manufacture late in 1877. See Mary Edwards Swan and K. R. Swan, Sir Joseph Wilson Swan, A Memoir (London, 1929), p. 43.

77. Werge, pp. 96-97.

fication of the process, amateur interest in photography increased very substantially.

The introduction of the gelatin process brought a highly significant reduction in exposure time. With the reduction of the exposure time to under one second,[78] the era of instantaneous photography began, and with it came significant advances in the usefulness of photography to science and the arts.

The discovery of the "ripening process" was one of the principal steps in the reduction of the exposure time. Joseph Swan, an English photographic materials and chemical manufacturer, developed a process of manufacture of dry plates in 1877, and while conducting experiments on the production of these plates, he noted that the sensitivity of the gelatin plates remained quite erratic. He finally traced the variability to the temperature and duration of cooking of the gelatin emulsion prior to spreading it on the glass plates. Through controlled heating of the emulsion, Swan increased the sensitivity of the plates very substantially. Rather than patent this process, Swan chose to keep it a manufacturing secret.[79] At about the same time, however, another Englishman, Charles Bennett, independently discovered the ripening process. He exhibited instantaneous photographs at

78. Gernsheim, History..., pp. 266-268.

79. Swan, p. 43.

a meeting of the South London Photographic Society on March 17, 1878, and at that time decided to publish details of his process. Hence, on March 29th he described his ripening process in The British Journal of Photography.[80] At first, he suggested heating the emulsion at a temperature of about 32° C. for several days in order to maximize the sensitivity. Later, he observed that, by increasing the temperature, the period of heating could be reduced to about an hour. This observation increased the practicality of the process for large-scale production.

Shortly after the development of the ripening process for gelatin emulsions, further studies and advances followed. Dr. Désiré Charles Emanuel van Monckhoven (1834-1882), a Flemish chemist who wrote a number of works on photographic chemistry and optics and also encouraged the founding of two important dry plate factories in Belgium, conducted some of the most important work in this area. In 1879, ~~in a newly-equipped laboratory in Ghent, he studied the~~ increase in sensitivity of gelatin silver bromide emulsions. At that time he observed that exposure of the emulsion to fumes of ammonia accelerated the ripening process. Moreover, he speculated that molecular changes in the silver halide salt caused the increased sensitivity. Others, including

80. Charles Bennett, "A Sensitive Process," Brit. J. Photog., XXV (1878), 146, and XXVI (1879), 133; compare with Werge, p. 102.

W. de W. Abney, J. M. Eder, and Captain G. Pizzeghelli, carried these investigations further during the 1880's. Friedrich Wilhelm Ostwald later offered the theory that the larger silver bromide particles increase at the expense of the smaller, more soluble ones and, thereby, cause the emulsion to increase in sensitivity.[81]

During the last quarter of the century, the rapid advances in chemical knowledge and theory stimulated further investigation of the nature of the photographic process, development, and fixing. A number of academic chemists investigated the silver-thiosulfate salts used as fixing agents. While retaining the idea of the formation of double salts which Lenz had suggested in 1841, another German chemist, Alfred Schwicker, in 1889 introduced structural concepts in order to account for isomeric forms of the double salts.[82] A decade later, the American chemists, Theodore W. Richards (1868-1928) and Henry B. Faber, studied the solubility of silver bromide and silver chloride in sodium thiosulfate and concluded that, though the double salts obtained by Lenz might exist in crystallized form, evidence pointed to the formation of a complex ion in solution. By studying changes in the freezing point caused by addition of silver bromide to

81. Eder, History..., pp. 427-437 and 778.

82. Alfred Schwicker, "Beiträge zur Kenntniss der Sulfite und Thiosulfite," Berichte der Deutschen Chemischen Gesellschaft, XXII (1889), 1728-1736.

a solution of sodium thiosulfate, they found that the freezing point increased and, therefore, concluded that such a rise could be produced only by a diminution of the number of active particles in the solution. Hence, they provided evidence for the formation of a complex ion.[83] The important investigations of Alfred Werner in inorganic complex formation during the 1890's may have prompted such considerations. In 1903, G. Bodländer, a German chemist and teacher in the Technische Hochschule in Braunschweig, clearly revealed the influence of Werner in a study in which he argued for the formation of two silver thiosulfate complexes. In this connection Bodländer made use of co-ordination numbers in discussing these complexes and their structure.[84] While academic chemists investigated these important salts, industrial chemists, especially those connected with the photographic industry, also gave them

83. Theodore W. Richards and Henry B. Faber, "On the Solubility of Argentic Bromide...," American Chemical Journal, XXI (1899), 167-172.

84. G. Bodländer, "Ueber einige complexe Metallverbindungen," Ber. Deut. Chem. Ges., (1903), 3933. Present day analysis indicates that two complex ions exist in solution:

$[Ag(S_2O_3)_2]^{-3}$ and $[Ag(S_2O_3)_3]^{-5}$. The probable mechanism of fixation is:

$$Ag^{+} + S_2O_3^{--} \longrightarrow (AgS_2O_3)^{-}$$

$$(AgS_2O_3)^{-} + S_2O_3^{--} \longrightarrow [Ag(S_2O_3)_2]^{---}$$

See C. E. K. Mees, The Theory of the Photographic Process (New York, 1954), p. 713.

their attention. For example, Auguste and Louis Lumière and Alphonse Seyewetz studied the salts formed in fixing baths. Though they sought primarily to solve some of the problems associated with the exhaustion of fixing baths, they provided further empirical data in this important field.[85]

The introduction of new organic developers in the last two decades of the century created a new problem. Traces of the new developers were carried into the sodium thiosulfate fixing solution and tended to discolor the solution because of atmospheric oxidation of the trace quantities. By making the solution acidic, photographers could greatly reduce such oxidation. Yet the addition of most acids to fixing solutions produces decomposition of the thiosulfate to sulfurous acid and sulfur. The latter interferes with the fixing process. The addition of sodium sulfite prevents this decomposition when acids are added. In 1889 Alexander Lainer (1858-1923), a professor of chemistry and physics in a photographic technical school in Vienna and later a dry plate manufacturer, first suggested the use of sulfites in acid fixing baths.[86]

85. A. and L. Lumière and A. Seyewetz, "The Limits of Useful Work in the Fixing Bath," Photog. J., XLVII (1907), 129. See also Lumière and Seyewetz, Brit. J. Photog., LIV (1907), 139.

86. This idea may have been derived from the addition of sulfites to developing solutions, as suggested by Berkeley in 1882; see Stenger, History of Photography (Easton, Penna., 1930), p. 33, and Eder, History..., p. 437. Effect of

At about the same time photographers began adding alum to fixing solutions in order to harden the gelatin so that it would not absorb so much water while in the fixing bath. This technique made the drying of negatives easier and faster than before.

A closely allied problem was also solved during the late 1870's and early 1880's. If negatives are too dense, either because of overexposure or overdevelopment, it is desirable to reduce the density. In 1876 Joseph M. Eder, a famous Viennese photochemist, photographer, and educator, noticed that potassium ferricyanide reacts with metallic silver and the newly formed complex is soluble in sodium thiosulfate. In 1883 the Englishman, E. Howard Farmer, suggested using a mixture of thiosulfate and ferricyanide as a reduction bath. Since that time such a reduction bath has been known as "Farmer's reducer."[87]

During much of the nineteenth century, the accumulation of many isolated facts and techniques provided the foundation for the advancement and progress in photographic tech-

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addition of acids to sodium thiosulfate:

$$\underset{\text{sodium thiosulfate}}{Na_2S_2O_3} + 2\,\underset{\text{acetic acid}}{CH_3COOH} \rightleftharpoons \underset{\text{sulfurous acid}}{H_2SO_3} + 2\,\underset{\text{sodium acetate}}{CH_3COONa} + \underset{\text{sulfur}}{S}$$

Effect of addition of acids and sodium sulfite:

$$\underset{\text{sodium sulfite}}{Na_2SO_3} + \underset{\text{sulfuric acid}}{H_2SO_4} \rightleftharpoons \underset{\text{sodium sulfate}}{Na_2SO_4} + \underset{\text{sulfurous acid}}{H_2SO_3}$$

See James G. Southworth and T. L. J. Bentley, Photographic Chemicals and Chemistry, 3rd ed. (London, 1957), pp. 52-53.

87. Eder, History..., p. 438.

nology. Even when people of scientific training became involved in photographic problems, their contributions tended to be empirical in nature. Though some theories of the latent image and the action of fixing agents were offered, photographic science, if such a term is appropriate, was in a primitive or highly empirical stage of development, lacking an integrated and systematic theory. However, one area of photography, developers, began to emerge from pure empiricism during the last decades of the century and soon developed a systematic theory. It was, perhaps, natural at this time when the German aniline dye industry was flourishing that substances similar to aniline dyes, such as aromatic reducing agents (developers), should receive close scrutiny, and in the march of advancing knowledge of structure and composition in organic chemistry, become the object of an integrated theory of developing action and structure. But it is important to note that it was the work of chemists employed by French and German photographic materials producers, many of whom were also connected with dye research and production, that brought forth the new theoretical formulations.

During the last years of popularity of the collodion process, photographers employed iron sulfate and alkaline pyrogallol as developers, but then they turned to a host of developers which had recently been discovered. An

American chemist, Carey Lea (1823-1897), while carrying out one of many of his photochemical investigations, discovered in 1877 that potassium ferrous oxalate acts as an effective developer for silver halides. During the next ten years he also discovered several other metallic developers, but none rivaled the importance of iron oxalate. With the advent of a new era in photography at hand, photographers soon employed Lea's iron oxalate as a successful agent for the new gelatin plates. They also used acidified pyrogallol, but soon alkaline pyrogallol became more common, replacing even the ammonia-pyrogallol developers because of its accelerating property.[88]

The most important work in photographic developers at this time focused on organic developers and the correlation of their structure with their properties. Most of these developers were substances which had been discovered earlier, but their developing properties had not been recognized. Abney in 1880 announced in <u>Photographic News</u> that hydroquinone possesses developing properties.[89] It was not very popular at first but later received support for its use from Joseph Eder and Viktor Töth (1846-1898) in Vienna. In the same year, Eder and Töth discovered that pyrocatechol is a suitable alkaline developer for gelatin plates. While studying this compound

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88. Compare Werge, p. 101; Mees, p. 538; Eder, <u>History</u>..., pp. 377 and 433; and Taft, p. 371.

89. W. de W. Abney, "A New Developer," <u>Photographic News</u>, XXIV (1880), 345. Hydroquinone:
HO  OH

and various bihydroxyl derivatives of benezene, they observed that the para-bihydroxybenzene (Abney's hydroquinone) and the ortho-bihydroxybenzene (their pyrocatechol) provide strong action as alkaline developers for silver bromide; however, the meta-bihydroxybenzene (resorcin) is not an effective developer.[90] Thus, Eder and Töth laid the first stone in the foundation of a theory of benzene derivative developers. The rapid advances which had been made in understanding of organic structural chemistry since the 1860's made such work possible. Also, the older generation, familiar with the origins of photography, had given way to a new generation of photographers with either advanced scientific or technical training. Eder, for example, had obtained his doctoral degree in chemistry from the University of Vienna. Thus, the time of the revolutionary change from the collodion process to gelatin emulsions also coincided with entrance of new and more highly trained people into the field. The combination of a new technology

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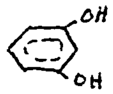
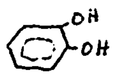
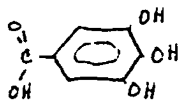
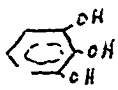
90. Werge, p. 106; J. M. Eder and V. Töth, "Neue Entwickler mit Pyrocatechin und Resorcin," Photog. Korresp., XVII (1880), 191.

Pyrocatechol: 

Resorcin: 

Note: the structure of the earlier organic developers were:

Gallic acid: 

Pyrogallol: 

and new personnel brought a vigor to photographic science and technology during the period 1880 to 1910 which sharply contrasts with the relatively dormant period from 1855 to 1880.

While young industrial chemists were discovering new organic developers, Herbert B. Berkeley (1851-1891) discovered an important improvement for both the new and old developing solutions. Berkeley had received his chemical training at Uppingham College and had concerned himself with photography. While employed by the Platinotype Company, London producers of cameras and photographic paper, he found a method of preventing staining of the negative by aerial oxidation of the pyrogallol. He discovered that by adding sodium sulfite to the developing solution he could retard aerial oxidation.[91] Shortly after this announcement in 1882, other photographers began adding sulfites to developing solutions containing other reducing agents.[92]

During the 1880's a number of new organic developers were discovered. Carl Egli and Arnold Spiller first

91. When plain developing solution is exposed, aerial oxidation occurs forming developer oxidation products which stain the gelatin emulsion. When a sulfite is added to the solution, it combines with the developer oxidation products to form compounds which are not highly colored and which are not retained to any extent by the emulsion. See Southworth and Bentley, p. 46.

92. Werge, p. 109; Eder, History..., p. 433.

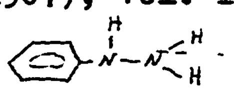
described hydroxylamine as a developer, opening up a new class of aromatic reducing agents.[93] In Berlin Dr. Emil Jacobsen patented phenylhydrazine in 1885 as a photographic developer and described the properties of various related compounds, including naphthylhydrazine.[94]

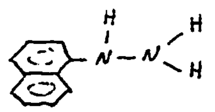
The end of the 1880's and the early 1890's saw the most significant discoveries of both new developers and developing theory. One of the most important figures in this movement was the German chemist, Momme Andresen (1857-1951). He had studied natural sciences at the Technische Hochschule in Dresden and had attended the Universities of Geneva and Jena, obtaining a Ph.D. at Jena in 1880. Following his graduation, he had worked for two years for Leopold Casella und Company at Frankfort, an early aniline dye producing firm, and then had spent another two years in the employ of the Schöllkopf Aniline and Chemical Works in Buffalo, New York. He returned to Germany and in 1887 began working in the chemical

93. C. Egli and A. Spiller, "A New Developer," Photog. N., XXVIII (1884), 613.

hydroxylamine: $\begin{matrix} H \\ H \end{matrix}\!\!>\!N{-}OH$

94. DRP #34342; Henri Silbermann, Fortschritte auf dem Gebiete der Photo-und Chemigraphischen Reproduktionsverfahren, 1877-1906... (Leipzig, 1907), Vol. I, pp. 129-130. DRP 36,746;

phenylhydrazine: 

α-naphthylhydrazine: 

laboratories of Aktiengesellschaft für Anilin Fabrikation (Agfa), where he initiated his investigations of aniline derivatives and photographic developers. Most of his work was with substances already discovered but whose developing properties had not been tested. Soon he recognized the importance of the NH_2 as an "effective group" in organic developing substances.[95] Following this lead, he discovered that para-phenylenediamine acts as a developer and obtained a German patent on it in 1888.[96] A year later he found eikonogen to be an effective developing agent.[97] Among the many organic developers which Andresen discovered about 1890, the most important commercially was Rodinal, a developer the production of which played an important role in the growth and success of the photographic division of Agfa.[98] In 1892 Andresen also demonstrated that hydrazine

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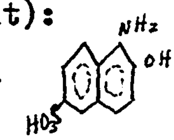
95. J. C. Poggendorff, Biographisch-Literarisches Handwörterbuch zur Geschichte der exacten Wissenschaften (Leipzig, 1936-1940), Vol. VI[1], pp. 55-56.

96. See DRP 46,495, 46,915, and 46,945. See also Silbermann, Vol. I, p. 130.

p-phenylenediamine: H_2N  NH_2

97. Eikonogen (2-napthol-6-sulfonic acid, 1-amino-sodium salt):

Na^+ 

See DRP #50,265 (1889); see Silbermann, Vol. I, p. 121.

98. Silbermann, Vol. I, p. 123; See M. Andresen, "Ueber Para-amidophenol als Entwickler," Photographische Mitteilungen, XXVIII (1891), 124; DRP #60,174 (1891);

Rodinal: H_2N  OH

Stenger, p. 32, refers to importance of rodinal to growth of photographic department of Agfa.

possesses weak developing properties in strongly alkaline solution.[99] While Andresen discovered a number of aniline derivative developers, he also carefully noted which aniline derivatives fail to act as effective developers. Out of this extensive work which he performed during his first five years at Agfa, he helped establish the basic theory correlating organic structure with developing activity.

At the same time, the Lumière brothers and their associate, Seyewetz, at the laboratories of the Lumière photographic materials company in Lyon, France, also proceeded with fundamental investigations of the structure and function of organic developers. Both Auguste (1862-1954) and Louis Jean (1864-1948), though they held only honorary doctorates, had a good knowledge of organic chemistry.[100] The Lumières' associate in all of their photographic researches, Alphonse Seyewetz (b. 1869), had obtained a doctorate of science at Lyon and had done extensive work in industrial photography and organic analysis.[101] The Lumières and Seyewetz, in the course of their investigations of organic developers and

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99. M. Andresen, "Zur Konstitution organischer Entwickler," Photog. Mit. XXVIII (1892), 286 and 296.

Hydrazine: H_2-N-N-H_2

100. Poggendorff, Vol. VI^{III}, pp. 1582 and 1586.

101. Ibid., Vol VI^{IV}, p. 2422.

their structure, introduced several important new developing substances, including Metochinon, a complex compound of metol and hydroquinone, and hydramin, a combination of hydroquinone and para-phenylenediamine. In 1894 they reported on an extensive study of aromatic hydroxylamines and added phenylhydroxylamine to the growing list of organic developers. During the remainder of the decade they carried out comparative studies of developing effectiveness of aromatic compounds with hydroxy and aminohydroxy substituents. They also examined numerous inorganic metallic substances and reported on their potential as developing agents.[102]

From 1890 numerous chemists sought new developers. Dr. A. Bogisch, a chemist in the photographic division of the J. Hauff chemical factory in Feuerbach, introduced metol,[103] glycin[104] and amidol.[105] About the same time Andresen also discovered amidol. Agfa brought this ~~developer on the market, but the Hauff company contested~~

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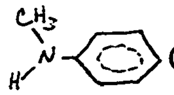
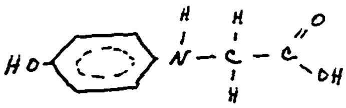
102. Mees, Chapter 14.

103. metol: p-methylaminophenol sulfate



OH + ½ H_2SO_4

See DRP#69,582 (1891) and #71,816(1891); see also Silbermann, Vol. I, pp. 123-124.

104. glycin: p-hydroxyphenylglycine 

DRP #75,505 (1891); Silberman, Vol. I, p. 125.

105. amidol: 2,4 - diaminophenol, dihydrochloride

the claims of priority of Agfa.[106] Dr. Fritz Hauff (1863-1935), who introduced several developing agents, also worked with Bogisch.[107] In 1899 Votoček made public his investigations of aromatic hydrazine derivative developers and, thereby, opened a new avenue of exploration.[108] At the turn of the century Dr. Hinricus Lüppo-Cramer discovered the developing properties of adurol.[109]

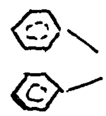

+ 2 HCl

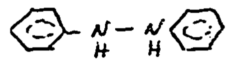
For one form see DRP#71,277 (1892) - J. Hauff. Silbermann, Vol. I, p. 124.

106. Photog. N., XXXVII (1893), 42.

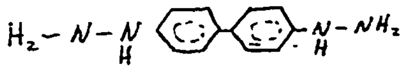
107. Stenger, p. 32.

108. Mees, pp. 543-544; examples:

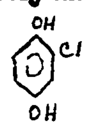
diphenylhydrazine:  N-NH_2

hydrazobenzene: 

The azo compounds were of considerable interest to German industrial chemists at this time because of their dyeing qualities. See especially the work of Otto Witt from 1876.

dihydrazinodiphenyl: 

109. adurol: chlorohydroquinone or bromohydroquinone

Silbermann (Vol. I, p. 121) points out that bromohydroquinone was marketed by Schering as adurol, while Hauff marketed chlorohydroquinone as adurol. In 1899 Agfa marketed as hydroquinone bromide a mixture of hydroquinone with alkalibromide. This is not identical with adurol. E. Schering patented halogen substituted hydrochinone, benzenecatechols, and pyrogallol as photographic developers, DRP #111,798: (Silbermann, Vol. I, p. 120.)

R. E. Liesegang, of an old photographic firm in Dusseldorf, studied inorganic developers containing salts of chromium, molybdenum, and tungsten.[110] Many other new developers of varying importance were synthesized and investigated by chemists in the laboratories of a number of German chemical companies, including E. Schering in Berlin, Ellon and Co. in Charlottenburg, Bayer and Co. in Elberfeld, Lucius and Brüning in Höchst, J. Hauff in Feuerbach, and Afga in Berlin.[111]

The significant result of these investigations of aniline derivative developing agents, beyond their importance in improving the quality and speed of photographic emulsions, was the development of a correlation between chemical structure and developing effectiveness. The key figures in formulating this theory were Andresen, the Lumières, and Seyewetz. Based upon their investigations from 1888 to 1892, a number of fundamental observations emerged. They noted, for example, that for a substance of the aromatic series to be a developer, two hydrozyl or

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110. Mees, p. 537.

111. See the following patents: Hauff: DRP 75,505; 71,816; 69;582; 71,277; 75,131; 102,755; 97,596;
Schering: 111,798;
Ellon and Co: 105,080;
Bayer and Co: 157,667; 149,123; 145,398; 159,874;
Lucius and Bruning: 142,489; 143,062;
Agfa: 50,265; 53,549; 76,208; 128,484; 129,587; and of course, those of Andresen.
This list is only a very small sampling.

two amino groups or a hydroxyl and an amino group must be present at the same time. This is not sufficient, however, but in addition, these groups must be in either the ortho or para position to each other. Furthermore, they found that while they could substitute alkyl groups for hydrogen of the amino groups without hindering the effectiveness of the compound as a developer, such substitution in the hydroxyl groups destroys the reducing quality requisite of a developer. However, they could substitute either hydroxyl, amino or alkyl groups, or halogen atoms for hydrogens of the aromatic ring without hindering the effectiveness as a developer. They also found similar principles to apply to polynuclear aromatic compounds. Subsequent studies, extending into the twentieth century, established the order of effectiveness of the various aromatic developers, depending upon ring position and substituent groups.[112]

Thus significant advances in knowledge and theory of organic developers and their use in photography came through the efforts of chemists interested in photographic chemicals. This was especially true of those chemists associated with the photographic industry in Germany, France, and Austria. The combination of (1) scientifically trained personnel, (2) industrial support for scientific research, protected by improved patent laws,

112. Silbermann, Vol. I, p. 24; Mees, pp. 546, 547, and 552.

especially in Germany and, (3) growing demand for photographic materials by the amateur as well as the professional photographers encouraged rapid progress in this area of photographic science and technology. In turn, chemistry obtained from these researches new knowledge of the structure and properties of the aromatic compounds.

In summary, science played an important role in the progress of photographic technology during the nineteenth century. Early in the century, advances in knowledge of silver halide salts, gallic acid, pyrogallol, and alkali thiosulfates laid the foundation for the discovery and rapid improvement of the photographic process. During the fifteen years following the introduction of the daguerreotype, leading scientists such as Fizeau, Regnault, Liebig, and Schönbein played important roles in improving the process. From the middle 1850's until the early 1880's, advances in photography were not as closely associated with chemists and chemistry as earlier. The discovery, investigation, and production of organic developers during the last decade and a half of the century renewed close association between chemistry and photography, but the contact was not with leading chemists of the day but principally with industrial chemists of good training. Without question, the influence of the German fine chemical companies played an important part in initiating interest in aniline derivatives as developers, and this

interest in photographic developers gradually brought some of these firms such as Agfa and Hauff into production of other photographic materials.

Chapter III

PHOTOGRAPHIC PAPER

Though technical advances in the making of negatives largely controlled the pace of progress in photography, progress in the making of positive printing paper was also important. Where this progress did not follow the pattern of advances in negative production, improvements were due to limited modifications of the basic processes rather than to significant innovations in technology.

Positive prints are the ultimate objective of photography. In the case of the daguerreotype, a positive was produced directly in the camera. During the first decade following the introduction of photography, the daguerreotype process was dominant; and, therefore, prints received relatively little attention. The negative paper processes used at that time, of course, required positive prints for the final production of the photograph, and photographers made these on paper. Talbot and Herschel, for example, produced positive prints on silver-salt sensitized paper by placing the negative over the sensitive paper and exposing it to sunlight for an extended period. After this long exposure, the portions of the sensitive paper exposed to the sunlight darkened and formed the photographic image. Then Talbot and Herschel fixed and dried the prints. This general method of producing positive prints was known as a printing out process.

These and other early photographers made the first

positive prints on paper which they treated with a saturated aqueous solution of sodium chloride or potassium iodide. After they dried the paper, they immersed it in a silver nitrate bath and then exposed it to the sun for printing. Though this method produced adequate photographs, it did not seriously compete with the superior daguerreotype process for two reasons. First of all, the sensitive salts penetrated the fibers of the paper and gave the print a sunken appearance. Second, these salted-paper prints tended to fade rather rapidly, a fault very frustrating to the owner who wished permanent photographs. As long as the dagerreotype process dominated the photographic scene, the salted-papers and their problems attracted relatively little attention; however, the successful change to the negative process about mid-century was furthered by the introduction of a new positive printing paper, albumen paper.[1]

Blanquart-Evrard, a French amateur photographer who later established an important photographic printing company at Lille, experimented with a variety of negative and positive processes during the late 1840's and early 1850's. He reported these efforts to L'Académie des Sciences of Paris, which duly published them in the Comptes rendus. From among these, his most significant

1. In photographic circles the word "albumen" was used instead of "albumin," inasmuch as albumen products were generally made directly from egg whites.

contribution was the introduction of albumen positive printing paper. Adding sodium chloride to egg white, impregnating paper with the solution, drying it, and then treating the surface with silver nitrate, he obtained a printing paper which was superior to the salted paper. The image was formed in the adhering albumen layer and therefore did not, like that on the salted papers, give a sunken appearance. Also, prints made on the albumen paper did not tend to fade as much as those on the salted papers.[2]

By the early 1850's, processes for producing positive papers included use of starch and gelatin as well as albumen. When the new glass-negative photography was first introduced, many photographers used heavily starched paper saturated with silver chloride, but by the 1860's, albumen paper had captured the trade and continued to dominate until the 1880's, when it began gradually to decline in use until the turn of the century.

In the early 1860's, some observers began to consider the possibility of use of a light-sensitive emulsion. In 1861 M. A. Gaudin, editor of La Lumière, a French photographic journal, experimented with emulsions of silver halide and collodion and produced positive printing paper by spreading a collodio-silver-chloride solution on paper.[3] In the same year, collodio-silver-halide emulsions were patented in England. In 1865 George

2. Comptes rendus hebdomadaires des seances de L'Académic des Sciences, XXX(1850), 663-665.

3. British Journal of Photography, XVIII(1871), 332.

Wharton Simpson (1825-1880), editor of Photographic News, an English publication, produced collodio-silver-chloride emulsion paper. Though it was more sensitive and permanent than albumen paper, it was not commercially produced until 1867. Even then it did not readily replace albumen paper.[4]

The problem of the photographic image sinking into the paper was entirely overcome by coating the paper with barium sulfate prior to application of the sensitive coating. In Paris in 1866 Martinez-Sanchez and J. Laurent produced positive printing paper using the baryta coating. The introduction of gold toning, similar to the toning of daguerreotypes as introduced by Fizeau in the early 1840's, aided in making positive prints more permanent.[5] Other efforts to gain improved permanency focused upon use of platinum salts as sensitive substances in place of the less stable silver salts. At the British Association meeting in 1859, C. J. Burnett suggested the use of platinum salts, but commercial production did not begin until 1873. Modifications suggested by Captain Pizzighelli and Baron von Hübl in 1882 made feasible excellent platinum

4. Helmut and Alison Gernsheim, History of Photography... (London, 1955), p. 284, claims 1868 for Obernetter's introduction, while Erich Stenger, History of Photography..., trans. E. Epstean (Easton, Penna., 1939), p. 49, claims 1867. It would seem that Stenger was in a better position to know.

5. Brit. J. Photog., LIV(1907), 837; Stenger, p. 50.

printing papers. However, the increasing price of the platinum metal during the last quarter of the century brought gradual abandonment of its use except for very high quality reproductions.[6]

As indicated earlier, gelatin was used as a base for printing paper in the early 1850's but without much apparent popularity. In the middle 1860's, suggestions for the use of gelatin silver chloride appeared again. Only after the successful introduction of gelatin emulsions as a negative coating did manufacturers commercially produce gelatin printing papers. Captain W. de W. Abney in 1882 produced the first printing-out gelatin chloride paper, and within a few years this paper was marketed as Aristotype.[7] The name Aristotype generally came to represent gelatin silver chloride printing-out papers, though in the United States photographers applied the term more broadly to include collodio-chloride printing-out papers as well.

The introduction of gelatin emulsions revolutionized not only the photographic process with regard to production of negatives but also the field of printing papers. At the time of particular interest in gelatin emulsions in the early 1870's, Peter Mawdsley of Liverpool suggested the use of gelatin silver bromide emulsions on paper. Though he eventually went into the dry plate

6. Gernsheim, pp. 282-283.

7. Photographic Journal, XXVII(1882), 155.

business in England, he did not capitalize on this improvement in photographic printing papers. In 1879 J. W. Swan did recognize the potential, patented the idea, and began production of such papers.[8] Because of the sensitivity of the bromide emulsion, an exposure of the paper to artificial light for only a few seconds permitted later chemical development of the image. The gelatin bromide papers significantly simplified the otherwise long and cumbersome printing process and made the photographer no longer dependent upon the sun for printing of photographs. This new form of printing paper was called developing-out paper as contrasted to that requiring longer exposure time called printing-out paper.

J. M. Eder (1855-1944) and Captain G. Pizzighelli, both of Vienna, described in 1881 the use of gelatin silver chloride paper which, because the chloride is less sensitive than the bromide, could be used either as a developing-out paper or a printing-out paper. In 1883 Eder also reported the use of a gelatin emulsion containing both silver bromide and silver chloride. Papers prepared with this emulsion were intermediate in sensitivity between those containing the two halide salts alone. Photographers also used this paper both as a developing-out paper and a printing-out paper.[9]

In spite of the superiority of the gelatin emulsion

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8. Mary Edmonds Swan and K. R. Swan, Sir J. W. Swan, a Memoir (London, 1929), p. 44.

9. Photographic News, XXVII(1883), 98; Joseph M. Eder, History of Photography, trans. E. Epstean (New York, 1945), pp. 443 and 447.

paper over albumen paper, especially with regard to speed and permanence, all photographers did not readily adopt the new papers. Indeed, many photographers changed from albumen to collodion, probably because the properties of albumen and collodion were more alike than those of albumen and gelatin.[10] Many photographers who changed from albumen to gelatin confined their use to gelatin printing-out papers rather than adopting the new developing-out paper. The increased precaution necessary in handling the highly sensitive developing-out papers may account for the early reluctance of photographers to adopt them. Also, many photographers checked the progress of their prints while the prints were being exposed and determined the correct exposure by visual judgment. With the developing-out papers, the photographer had less control over the results since the exposure time was very brief.[11] Therefore, in the 1890's when Velox, a developing-out paper which compromised on some of the properties of both types of paper, first appeared, it was natural that many photographers soon switched from using these other papers and began using Velox.

Leo H. Baekeland, a Belgian-American industrial chemist, developed Velox paper and thereby brought a significant innovation in printing paper production.

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10. For example, both were water soluble.

11. Werge discusses these problems, especially with regard to the introduction of gelatin bromide plates. For example, John Werge, Evolution of Photography (London, 1890), p. 95.

By modifying the ripening of the silver chloride gelatin emulsion and eliminating a washing step prior to coating, he produced a developing-out paper which was much slower than the bromide papers and therefore could be handled in rooms illuminated by dim incandescent gas or carbon filament lamps. Yet Velox paper was sensitive enough to be exposed fully when placed at a short distance from artificial illumination for about one minute. By the end of the century, these properties made Velox very popular, especially among amateur photographers.[12]

At the end of the century, also, the use of diazo dyes in conjunction with silver salts brought competition for Velox. With the help of some of these newly-discovered sensitizing dyes, the color sensitivity of printing paper was extended into the blue portion of the spectrum. Early in the twentieth century major producers such as Eastman Kodak acquired the production facilities for some of these new papers, and these improved papers were also marketed under the name of Velox.[13]

Also at the end of the century, photographers began to change their preference from gloss paper to mat paper. Manufacturers produced the mat paper by adding starch to the emulsified silver halide in gelatin. Commercial

12. C. E. Kenneth Mees, "Leo Hendrik Baekeland and Photographic Printing Papers," Chemistry and Industry, XXVII(1955), 1134-1138; see Baekeland's letter in Photog. J., LXX(1930), 491; see also Chapter VII, note #48.

13. Mees, p. 1137.

photographers as well as workers concerned with photomicroscopy, Roentgen photography, and astronomical photography used mat papers.

Thus, progress in the technology of photographic printing papers followed the pattern of introduction of binding materials in negative photography. Much of the change from 1850 to 1900 resulted from increasing empirical knowledge about the properties of collodion and gelatin and from modifications and substitutions in older processes. Communications about progress in printing paper technology appeared in the scientific journals as late as the early 1850's and in the photographic journals throughout the 1850's. By the 1860's, however, when photographic paper manufacturers became established, information was less available, and processes became patented. By the 1880's, an increasing number of people working in this area possessed good academic training in chemistry, in particular people such as Eder, Pizzighelli, and Baekeland. Specific advances in chemistry did not, however, have a strong influence on the direction of progress. The work on diazo compounds initiated in the early 1860's did make possible improvements in the Velox paper at the end of the century; but, in general, photographic paper technology drew more heavily from photographic negative technology than directly from chemistry. Because of the early entrance of manufacturing concerns in the field, detailed knowledge of processes became less available than in most areas of

photographic science and technology.

Chapter IV

DEVELOPMENTS IN PHOTOGRAPHIC OPTICS

The quantity of light reaching the photosensitive surface is of prime importance in determining the required exposure time for a photograph. Therefore, during the period 1839-1900, photographers, practical opticians, and scientists focused attention upon the control of the quantity of light and the quality of the image imposed upon the sensitive surface. As a result of their efforts during this period, the techniques of developing excellent optical systems for cameras improved to the extent that by the end of the century theoretical lens design had largely replaced the tedious trial-and-error methods of the early period. The development and commercial production of new types of glass with a wide variety of optical characteristics, due in large part to the activities of the Zeiss Optical Company, provided for the first time new types of optical systems for photographic use.

While the following discussion will attempt to describe the highlights in the development of photographic optics during the nineteenth century, the emphasis will be placed upon those significant advances in both theory and practice which demonstrate interaction between the trained physicist, be he theoretical or practical, and the practical opticians and business firms. It is impossible

to treat in detail each of the large number of photographic objectives developed over this sixty-year period. Furthermore, to do so would be redundant, because an excellent history of photographic objectives already exists, Moritz von Rohr's Theorie und Geschichte des Photographischen Objektivs. Frequent reference will be made to this work in the following discussion.

DEVELOPMENTS IN OPTICS PRIOR TO INTRODUCTION OF PHOTOGRAPHY

Though the chemical basis of photography was successfully developed only in the late 1830's, the camera existed from a much earlier time. The pinhole effect, the casting of a reversed, inverted image by light rays passing through a very small aperture, was known from at least the eleventh century when the Arabic philosopher Alhazen (965-1039) described this phenomena. Other natural philosophers of the Middle Ages and early Renaissance, such as Roger Bacon (1214-1294), John Peckham (d. 1292), and Leonardo da Vinci (1452-1519), also described the effect. A darkened room with such an aperture exposed to an externally lighted scene became known as a camera obscura (Latin for "dark chamber"). As early as 1550 Jerome Cardan (1501-1576) introduced a convex lens at the aperture, while portable models of the camera obscura came into use during the late sixteenth century. Giovanni Battista Della Porta (1538-1615) introduced into a portable camera obscura a mirror in order to provide an upright image. His

discussion of the camera obscura in his popular work Magiae Naturalis (1558) did much to bring attention to this instrument. In 1612 Christopher Scheiner (1575-1650) used this instrument in connection with a telescope in order to observe sun spots. Furthermore, Johann Kepler (1571-1630) dicussed the optical principles in his Dioptrice (1611). During the eighteenth century the reflex camera obscura became popular for drawing and artistic work. Early in the nineteenth century William Hyde Wollaston (1766-1828) made a further modification of the instrument by adding another mirror and thereby producing a camera lucida, a popular device for tracing scenes directly from nature. Therefore, by the early part of the nineteenth century the portable camera obscura was generally known and even produced for sale by leading opticians such as Charles Chevalier in Paris.[1]

In the one hundred years prior to the successful implementation of a photographic process, awareness and interest in the problems of optical systems gradually increased. Chromatic aberration posed one of the major problems of this period. Late in the seventeenth century Isaac Newton concluded that the refractive and dispersive

1. Good summaries of the development of the camera obscura are provided by Moritz von Rohr, Theorie und Geschichte des Photographischen Objektivs (Berlin, 1899), pp. 83-92, and Helmut and Alison Gernsheim, History of Photography (London, 1955), pp. 1-12.

powers of different glasses were proportional, and, therefore, combinations of lenses, even of different kinds of glass, would not eliminate chromatic aberration.[2] At about the same time English glass makers developed lead glass according to Venetian crystal formulas.[3] In 1722 Chester M. Hall demonstrated that this lead glass differs from crown glass very little in refractive power, but its dispersive power is more than double that of crown glass. Utilizing this difference in refractive and dispersive powers, John Dollond began in 1758 producing achromatic objective lenses for telescopes. This work became the foundation for improved telescope objectives such as those produced by Joseph Fraunhofer in the early nineteenth century.

Lens makers, however, could not achromatize microscope objectives as early as telescope objectives. The combination of chromatic and spherical aberration and diffraction effects brought the compound microscope into general disrepute during a large part of the eighteenth century and the first quarter of the nineteenth century.[4]

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2. Isaac Newton, Opticks..., 4th ed. of London (1730), (New York, 1952), Bk I, Part I, Exp. 16, pp. 86-107. See esp. p. 102.

3. W. A. Thorpe, English Glass (London, 1935), pp. 150-162.

4. For example, Bichat made his histological studies without the aid of a microscope. Of course, even where the compound microscope was distrusted, the simple microscope was employed. Maria Rooseboom, Microscopium (Leiden, 1956), pp. 34-37.

Sir John Herschel demonstrated mathematically in 1821 that a meniscus and double convex lens combination with certain curvatures of the four surfaces could correct for spherical aberration for paraxial rays. He called this lens an aplanatic doublet.[5] In 1823 and 1824 Selligue, a French physicist, achromatized a lens system consisting of four compound lenses, but he did not correct the system for spherical aberration. During the 1820's other people interested in optics also sought to achromatize and to remove spherical aberration from microscope lens systems. Yet the solution to the problem of correcting for both aberrations at the same time came slowly. Joseph J. Lister, however, by 1830, had put together Selligue's combination but had reversed some of the lenses and had found that by ignoring the chromatic aberration of each individual lens in the combination and dealing only with the chromatic aberration of the system as a whole, he could obtain good correction for both chromatic and spherical aberration.[6] From 1830 the compound microscope became a popular, reliable, and important instrument, creating an increased

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5. Philosophical Transactions of the Royal Society of London, CXI (1821), 222. Note that Herschel meant by aplanatic that spherical aberration had been eliminated for paraxial rays. Later, Steinheil used the term to mean that both spherical aberration and coma were eliminated.

6. Rooseboom, pp. 17-37; "Anatomy," Encyclopaedia Britannica, 9th ed., I, 817-818.

demand for optical products. As a result, many opticians gained new experience in practical optics and sought to experiment upon and improve the lens systems of microscopes.

During the first quarter of the nineteenth century, Joseph Fraunhofer (1787-1826) introduced optical investigations which led to improved optical instruments. At the Optisches Institut of Reichenbach, Utzschneider, and Fraunhofer at Benediktbeuren, near Munich, he accurately determined the dispersive and refractive indices of flint and crown glass. This optical institute, which became famous for its production of quality optical products, had been founded in 1809 and was the center of significant optical studies until the time of Fraunhofer's death. While there, Fraunhofer laid the foundation for calculating the requisite surfaces for telescopic objectives, but in order to carry out the calculations he had to obtain accurate optical constants. Fraunhofer's discovery in 1814 of emission and absorption lines in spectra enabled him to employ these "benchmarks" in his index determinations.[7] Fraunhofer's methods and results were standard in optical workshops for at least half a century. For a time the famous Swiss glassmaker, Pierre Louis Guinand (1748-1824), worked with Fraunhofer at Benediktbeuren. Guinand had experimented with the production of flint glass from 1775

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7. Discussion of Fraunhofer's work: Photographische Korrespondenz, LXII(1926), 57-67; Moritz von Rohr, Joseph Fraunhofers Leben, Leistungen, und Wirksamkeit (Leipzig, 1929); Rohr, Theorie..., pp. 283-285.

and continued his experiments into the early nineteenth century. When he continued to have difficulty with streaks and straie in the glass, he moved in 1807 to Benediktbeuren where he and Fraunhofer collaborated in producing optical glass. Soon Guinand developed methods of producing straie-free glass, and Fraunhofer employed this glass in producing telescope objectives such as those made for Bessel and Struve. Fraunhofer and Guinand continued their collaboration for about ten years, bringing production of telescope objectives to a high level of achievement. Even after Guinand returned to Switzerland, Fraunhofer continued to experiment with glass, but after his death his achievements in glass technology were largely forgotten. Guinand conveyed his secret process of glassmaking to his sons, who in turn made high quality optical glass during the first three quarters of the century. Thus, because achievements in optics were confined within the limitations of the types of glass available, these men helped to expand the potential of optical design by producing large disks of glass of optical quality and by developing methods of accurate index determination.[8]

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8. For discussion of Guinand and his work see: René Taton, History of Science: Science in the Nineteenth Century, trans. A. J. Pomerans (New York, 1961), p. 152; LeHoefer, Nouvelle Biographie Generale (Paris, 1855-1866), XXII, 750; David Gill, "Telescope", Encyclop. Brit., 9th ed., XXIII, 139; Felix Auerbach, The Zeiss Works and the Carl Zeiss Foundation in Jena, trans. R. Kanthack (London, 1927), p. 18; Rohr, Theorie..., pp. 325-334. There is considerable confusion concerning Guinand's death date. Rohr's date was used here.

In the 1820's the English became concerned about the quality of glass produced in England and brought the problem to the attention of leading scientists of the day. The Astronomical Society in London appointed a committee to study the problem. The members of this committee, including Michael Faraday, John Herschel, G. Dollond, and P. M. Roget, concluded that the solution of the problem of optical glass production lay more in the mechanical realm than in the chemical; however, as the result of Faraday's own investigations, he developed an easily melted glass which became known as Faraday's heavy glass.[9]

For the next fifty years the lack of good optical glass with a variety of differing optical characteristics remained a serious limitation for practical opticians. In spite of a number of investigations by persons of optical interest, including William V. Harcourt, George G. Stokes, J. Hopkinson, and H. Schroeder,[10] significant advances did not materialize until the scientific studies of Schott at Jena in the early 1880's. The history of Jena glass will be discussed later.

In theoretical optics much attention was focused during the first half of the century upon the debate between the wave theory of light and the emission theory. The success of Fresnel's mathematical interpretations of

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9. Rohr, <u>Theorie</u>..., pp. 333-334.
10. <u>Ibid</u>., pp. 335-336.

diffraction effects based upon the wave theory of light had converted many scientists to his point of view by 1830. It remained a moot question, however, until mid-century when Foucault and Fizeau made terrestial determinations of the velocity of light. After they demonstrated that the velocity of light in air exceeds that of light in a denser medium, the wave theory became generally accepted in scientific circles. Geometrical optics remained fairly aloof from the debate since most answers to the decisive questions rested upon phenomena in physical optics. Substantial works on geometrical optics from preceding centuries, including those of Kepler, Newton, and Euler, provided a foundation for understanding the basic principles. Early in the nineteenth century numerous published papers treated specific problems in geometrical optics. These included studies by George B. Airy (1801-1892),[11] Friedrich Wilhelm Bessel (1784-1846), and John F. W. Herschel (1792-1871). During this period William Rowan Hamilton (1805-1865), the famous Irish mathematician, and Johann Karl Friedrich Gauss (1777-1855), the reknowned German mathematician and physicist, wrote important comprehensive theoretical treatises dealing

11. Basic investigation of distortion, curvature of field and astigmatism of camera obscura objectives in 1827. Rohr, Theorie..., p. 91. See "On the Spherical Aberration of the Eye-pieces of Telescopes," Cambridge Philosophical Transactions, III (1830), 1-64.

with geometrical optics. In 1824 the youthful Hamilton set forth a theory of systems of rays in which he independently reduced geometrical optics to algebra, much in the manner that Malus (1775-1812) had in 1807. He based his approach on what he called a characteristic function in which he assumed that the action of light or time of transversal was minimal (reminiscent of Fermat's principle). He also made the important discovery of conical refraction. Unfortunately, Hamilton's theoretical work appeared to have little influence on practical opticians until very late in the century.[12]

Another important scientific figure of the early nineteenth century, Johann K. F. Gauss, contributed significantly to the theory of geometrical optics. He published his major work in optics, Dioptrische Untersuchungen, in 1840, but he claimed, and his correspondence confirms, that he knew the contents of this work for more than forty years prior to publication. When Bessel published his determination of the error involved in the calculation of the focal distance of the Königberg heliometer objective,

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12. Robert Perceval Graves, Life of Sir William Rowan Hamilton (Dublin, 1882), pp. 228-231; Rohr observed: "Eine Anwendung auf die Praxis der optischen Instrumente schient er aber von seinen Formeln nicht gemacht zu haben", Theorie..., p. 92; see also Dictionary of National Biography, XVIII, 1119.

he assumed that the usual lens formula ($1/0 + 1/i = 1/f$) was correct for lenses of finite thickness. This error prompted Gauss to collect his ideas on the subject and publish them. Like Hamilton, he algebracized geometrical ray-tracing and developed image formulas for simple lenses as a function of principal points and focal lengths. His investigations, however, limited themselves only to narrow pencils of paraxial rays. This work did influence theoretical optical physicists, such as Steinheil and Seidel, but it only provided the foundation for their more specialized work.[13]

PHOTOGRAPHIC OPTICS, 1839-1865

When the early photographic experimenters began equipping themselves with cameras, the state of optics at the time influenced the speed and quality of their process. When Niepce began his work, he equipped his home-made cameras with very crude condensing lenses, but in the middle of the 1820's he turned for assistance to Charles Chevalier, the famous Parisian optician, who obtained his optical glass from Guinand and his sons. In 1828 Niepce employed a non-achromatized Wollaston periscopic lens. When he collaborated with Daguerre, he obtained a camera with a similar lens but one which was achromatized, reflecting the progress in optics in the interim.[14]

13. Guy Waldo Dunnington, Carl Friedrich Gauss, Titan of Science (New York, 1955), pp. 170-172.

14. Joseph M. Eder, History of Photography, trans. E. Epstean (New York, 1945), pp. 197-199.

In fact, Rohr argues that Daguerre may well have stimulated Vincent and Charles Chevalier to achromatize the Wollaston meniscus lens at this time.[15]

A number of optical problems confronted the early photographers and their opticians. By 1839 lens makers had made progress in solving the problems of achromatization and production of good glass of uniform quality, largely because of the efforts of opticians to produce good quality microscope objectives. Photographic objectives, however, produced some unique problems. One of the most important requirements of a photographic objective was for it to gather as much light as possible in order to reduce the required exposure time;[16] yet the larger aperture brought with it greater spherical aberration. Other requirements for photographic objectives included flatness of field, wide angle of view, and freedom from distortion. High definition, such as was desirable in microscope and telescope objectives, was of less importance in photography, where many photographers preferred a moderate amount of diffusion of focus. Therefore, they tolerated some residual aberration. The type of lens, whether used as a landscape or portrait lens, influenced the

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15. Rohr, Theorie..., p. 93.

16. During the late 1840's, the 1850's, and the 1860's there was considerable competition among optical firms, such as Voigtländer and Busch, to produce the largest aperture portrait lenses. By 1855 lenses had reached a foot in diameter. The Gernsheim Collection at the University of Texas includes some of Voigtländer's giant portrait lenses.

specific optical characteristics required. For example, a landscape lens required less light-gathering power than did a portrait lens. On the other hand, the landscape lens required a larger field of view.

Reversal of the image presented a unique problem for daguerreotype cameras. Because the daguerreotype was a direct positive process, the image had to be reversed by means of a prism or mirror in order to give correct orientation. During the early 1840's opticians began to equip cameras with such reversing features. Later, when the change was made from the daguerreotype to the wet collodion process, another problem presented itself: the focal distance differed in the two processes. Eventually, photographers concluded that the position within the sensitive layer at which the image was chemically recorded caused the difference.

The difference in focal length for visual and chemical rays presented another problem which came to attention in the early 1840's. In 1840 Townson in England first noted this focal difference.[17] Soon Claudet made thorough studies of it and published them in numerous French journals.[18] These early investigators stimulated Andrew Ross, the

17. Philosophical Magazine, XV (1840), 381; see also note #24.

18. In addition to books published on photography, Claudet dealt with the subject in Comptes rendus hebdomadaires des Séances de L'Académie des Sciences, XVIII(1844), 954 and XXXII(1851), 130.

important London optical instrument maker, and N. P. Lerebours, a Parisian optician, to construct lenses which took account of this focal difference.[19]

At the time of introduction of the photographic process, most optical instrument makers employed trial-and-error methods in their designs of optical systems. In spite of the work of Fraunhofer in calculation and design of optical surfaces, most optical equipment producers of this period were unable to employ methods of mathematical ray-tracing in their works. This remained generally true until well past mid-century, but by the end of the century the increasing success of firms employing physicists and mathematicians to calculate lens systems had brought these firms to the position of reputation and leadership in production of quality photographic objectives. Therefore, the area of photographic optics vividly demonstrates the increasing tendency toward close association among science, technology, and business during the nineteenth century.

By 1839 three opticians were playing a significant role in the production and general improvement of photographic objectives. Chevalier in Paris, who had produced camera obscura lenses for some years, began production of photographic lenses even before the August announcement of the daguerreotype process. Daguerre gave an exclusive license for production of photographic equipment to Giroux,

19. Rohr, <u>Theorie</u>..., p. 150.

but Giroux contracted with Chevalier to produce the optical needs. At first Chevalier supplied lenses like those originally used by Daguerre (Wollaston single achromatic lenses). He made the lenses from glass supplied by Guinand's sons and achromatized the lenses by methods established by Fraunhofer. The lens possessed a focal length to aperture ratio of f14, a very slow lens by modern standards. When the demand became very great, however, Giroux also turned to the Parisian optician, N. P. Lerebours (1807-1873), who utilized, at first, an even poorer meniscus lens, one with an f number of 17.[20] In London Andrew Ross (1798-1859), an English optician who had played an important role in microscope production since 1830, produced a few photographic objectives in 1840. He used a lens similar to that of Chevalier. Photographers used this, like the French lens, for landscape photography because the small aperture could not gather sufficient light for portrait purposes. The initial insensitivity of the silver iodide surface and the slow lens, of course, posed serious limitations for the daguerreotype process in its early days. These three opticians, as well as others, sought to solve one problem by increasing the size of the lens and attempting to correct the resultant increase in spherical aberration. By means of their trial-and-error methods,

20. Helmut Gernsheim, L. M. J. Daguerre (New York, 1959), pp. 109-110; Rohr, Theorie..., pp. 89-93; Hoefer, X, 258, and XXX, 866.

they made progress, but it remained for a cooperative effort between a physicist and a practical optician to solve effectively the problem.

Joseph Petzval, an Austrian physicist, designed the first and probably most successful portrait lens and then turned the design over to the Viennese optical company of Voigtländer for commercial production. The story of the design and production of this lens well illustrates an early cooperative endeavor among pure science, technology, and business. Joseph Max Petzval (1807-1891) was born in Bela, Hungary, and studied engineering at the University of Budapest, where he became an assistant in 1832. In 1835 the University of Budapest appointed him Professor of Mathematics. Because of his talent, the University of Vienna called him in 1836 to occupy the chair of mathematics previously held by A. von Ettingshausen, who continued on the faculty and became a close associate of Petzval. During 1839 Ettingshausen traveled at state expense to Paris in order to study the progress of the physical sciences in France. He arrived in Paris at the time of great excitement over the Daguerre process and attended in August the meeting at the Academy of Sciences where Arago presented his description of Daguerre's photographic process. Later, Ettingshausen learned the art from Daguerre himself and also discussed the optical problems with Charles Chevalier. Upon his return to Vienna later in the year, Ettingshausen practiced daguerreotypy, using one of Chevalier's weak

lenses. Realizing that this lens could not be used in portrait photography, he discussed the problem with Petzval and encouraged this mathematician, who also had an interest in optical theory, to calculate the optics of a photographic lens of high light-gathering power for both landscape and portrait purposes. Petzval began to study the problem and soon abandoned the Chevalier-type lens. However, he realized that he could proceed no further without exact knowledge of refractive and dispersive indices. As a theoretician and not a practical optician, he did not know of Fraunhofer's methods. Therefore, upon Ettingshausen's recommendation, he turned to Friedrich Voigtländer, owner of the old established optical firm in Vienna, who obtained for him the optical constants determined by the Fraunhofer process.[21]

During late 1839 and early 1840 Petzval advanced his design based upon a large number of ray-tracing calculations. Archduke Ludwig, who at the time held the position of General Artillery Director, assigned as many as ten young artillerymen who knew mathematics to Petzval to assist in the tedious calculations. After completion of the designs of both portrait and landscape lenses, Petzval turned the designs over to Voigtländer for construction. Attention at

21. Petzval's life and work are discussed in the following sources: Photog. Korresp. XXXIX(1902), 395; M. von Rohr, Photog. Korresp. XXXXIII(1906), 266; Eder, pp. 290-303 (Note: drawn largely from Dr. Ermenyi, Dr. Joseph Petzvals Leben und Verdienste, 1903); Rohr, Theorie..., pp. 248-251.

the time focused upon the portrait lens because of demand for such a lens. Therefore, Voigtländer confined construction at this time to just the Petzval portrait lens. Voigtländer completed the first lens in May of 1840 and successfully tested it in Vienna. Soon he began commercial production of the lens, and in a short time it became world famous, especially because of its low f number, f 3.7. Even though production was licensed only in Austria and, therefore, it could be freely produced elsewhere, the demand was so great that Voigtländer alone by 1862 had produced 10,000 of these lenses. Unfortunately for Petzval he had not realized the commercial potential of his work and, therefore, had not protected it by patent or contract with Voigtländer. Hence, in spite of the commercial success of the lens, Voigtländer only gave Petzval a small sum ($1000) for the work which reaped handsome profits for the firm. As a result, cooperation between Petzval and Voigtländer came to an end by 1845.[22] Use of mathematical ray-tracing techniques in photographic objective design, so successfully employed by Petzval and implemented by Voigtländer, did not again appear for some time. Part of the reason for this delay may stem from the lack of interest and training in mathematical optics by practical opticians and in practical optics by mathematical physicists. In addition, the long calculations required by such methods may have further

22. <u>Ibid</u>.

lessened interest in the technique. It appears that this initial success in cooperation between science and production floundered, however, upon the failure of Voigtländer and, subsequently, other optical firms to appreciate fully the value of science in the design of optical products.

In France Chevalier also had turned to producing a portrait lens, but he utilized the customary trial-and-error methods of design. He finally produced a lens which could be converted readily from a landscape to a portrait lens and, therefore, had great versatility. It also employed an image-reversing prism which attracted the attention of practitioners of the daguerreotype process. In 1841 the Société d'Encouragement in Paris offered a prize for improvement of photographic lenses. Both Chevalier and Petzval competed for the prize with their portrait lenses, but Chevalier won first prize while Petzval won second. The award may have been granted as much for the novel features of the Chevalier lens as for the optical quality. In terms of popularity, the Petzval portrait lens exceeded that of Chevalier's lens, and most photographers recognized it as optically superior.[23]

As photographers became more discriminating, the focal difference between chemical and visual rays became

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23. Gernsheim, Daguerre..., pp. 109-110; Eder, pp. 294-295. Despite Eder's chauvinism he is probably correct on the essentials.

more important.[24] Andrew Ross in London and N. P. Lerebours both followed the investigations of Claudet on this matter and in the mid 1840's brought out lenses which corrected for focal difference. The Petzval lens possessed this focal difference because Petzval had used the Fraunhofer visual ray constants in the calculations of the design. Though the short focal distance made the focal difference relatively small, the error was later corrected in this lens.

The initial advanced position of Chevalier and Lerebours in production of photographic objectives put them in the lead for production of such lenses during the early years of the daguerreotype process. Yet the English opticians and amateurs soon came into a prominent position in the field. Although Voigtländer himself placed his Petzval lens on sale in England, the English optical firms of Davidson and Ross duplicated the unpatented Petzval portrait lens in the early 1840's.[25] This lens remained popular for some time. From the optical workshop of Andrew Ross came improvements in landscape lenses with

24. The focal point of a lens, of course, is a function of the wavelength of light. Visual focus at this time utilized the wavelength of light at about the sodium D line in the visual spectrum; however, the wavelength of light most effective for photographic purposes is at the violet end of the spectrum. Therefore, the photographic image would be slightly out of focus when an optical system designed for visual purposes was used.

25. Rohr, Theorie..., pp. 151 and 412-413; John Werge, Evolution of Photography (London, 1890), p.33.

special attention being paid to wide-angle lenses. James T. Goddard (d. 1864), a practical optician without scientific training, endeavored to employ mathematical techniques in lens design, but his efforts were without success. After Petzval's new landscape lens appeared in 1857, Goddard used trial-and-error methods to lessen the distortion in this lens.[26] Thomas Grubb (1801-1878), another important figure in the early years of English photographic optics, started an optical shop in Dublin and gained a reputation for his precision instruments. He produced telescopic objectives and mirrors for observatories in Melbourne and Vienna. He assisted Lord Rosse in producing his famous reflecting telescope. Though he had no scientific schooling, he possessed a thorough knowledge of theoretical optics. He was elected to membership in the Dublin Academy, the Royal Society of London, and the Royal Astronomical Society. In photographic optics he demonstrated that the French under-corrected their landscape lens for spherical aberration. Furthermore, he produced in 1858 a crown-flint glass single landscape lens free from spherical aberration. He engaged in vigorous debates with other leading optical producers, especially over the construction of aplanatic lenses for photography. He did, however, employ trial-and-error methods for most of his work. His failure to secure the patent on his landscape lens discouraged his further work

26. Rohr, Theorie..., pp. 163 and 181-183.

in photographic optics.[27]

Another Englishman, Thomas Sutton (1819-1875), also influenced photographic optics during the first quarter century of the history of photography. Sutton, in contrast to most other English, French, and American workers in the field, possessed a scientific education. He studied mathematics at Cambridge and in 1846 scored as 27th wrangler. From an early date he took an interest in photography and carried out numerous optical and chemical experiments related to photography. For a time he acted as a lecturer in photography at King's College and then in 1856 founded Photographic Notes, an English journal. Unfortunately, much of Sutton's influence was negative. His scientific education gave him a confidence which may have extended beyond its competence. He sharply critized the work of Thomas Grubb, John H. Dallmeyer, and Joseph Petzval, especially attacking the mathematical efforts of Petzval and Grubb. By the end of his life, he found that he had been attacking the wave of the future, as Steinheil's work, incorporating mathematical techniques, ushered in a new era in photographic optics.[28]

During the 1850's government agencies in Vienna encouraged Petzval to calculate a new landscape lens. He revised the design of the landscape lens he had calculated in 1840, and Dietzler, a local optical firm, began production

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27. Ibid., pp. 164-166, 183-188, and 413-414; Dict. Nat. Biog., VIII, 744.

28. Rohr, Theorie..., pp. 194-200 and 430-431.

of this lens in 1857. Practical opticians such as James Goddard initiated modifications of this design. This lens did not enjoy the popularity of Petzval's portrait lens, perhaps due to inadequacies of the producer Dietzler, who eventually went out of business.[29]

Andrew Ross, the most important English producer of photographic lenses, died in 1859. A son and a son-in-law assumed responsibility for two separate divisions of the firm. The latter, John H. Dallmeyer, proved the more progressive and successful of the two. He was born in Prussia and had obtained there an education in the lower schools which included the study of science and mathematics. He had spent three years as an apprentice to an optician at Osnabrück before emigrating to England. Ross had employed him in his workshop, and eventually he had become a science adviser, in charge of testing and finishing optical apparatus. When he gained independence following the death of his father-in-law, he actively sought improvements in photographic objectives. Sir John Herschel brought attention to him by recommending his work in an article in the 8th edition of the Encyclopaedia Britannica. Among his many outstanding designs, Dallmeyer developed an improved version of Petzval's portrait lens, a triple achromatic landscape lens, and a single wide-angle landscape lens. Though he did not employ mathematical techniques for

29. See note #20.

design of lenses, his practical knowledge made him a leader in the field. His achievements were recognized with his election to both the Royal Astronomical Society and the Royal Microscopical Society.[30]

Photographers in the United States came to depend upon foreign optical firms for quality optics and cameras. The major supply houses, E. and H. T. Anthony and Company and the Scovill Manufacturing Company, carried the important new lenses designed in Europe.[31] The Langenheim brothers, when they emigrated from Germany to Philadelphia in the early 1840's, brought with them the Petzval-Voigtländer lens.[32] C. C. Harrison, the American optician and leading camera manufacturer, developed in 1860 the globe lens, a symmetrical doublet used as a landscape lens. Later, C. B. Boyle, optical director of the American Optical Company, patented a modification of the globe lens in what he called the ratio lens. He granted production rights to the Scovill Manufacturing Company, one of the two largest camera producers in the United States at the time.[33] Because activity in optical design did not flourish in the United States, most photographers desiring

30. Dict. Nat. Biog., V, 400-402; Photographic Journal, XIV (1869), ii; British Journal of Photography, LIV (1907), 942; Rohr, Theorie..., p. 190.

31. See, for example, Humphrey's Journal for 1855; see also, Daguerreian Journal, I (1851), 190.

32. Eder, pp. 289 and 302.

33. Rohr, Theorie..., pp. 174, 176, and 177.

high quality equipment depended throughout most of the century upon the more vigorous and inventive producers across the Atlantic.

Thus, during the first twenty-five years of photographic objective production, new ideas came largely from amateurs or practical opticians utilizing trial-and-error methods for determining new designs. The revival of interest and production of compound microscopes just prior to the commercial introduction of photography laid the foundation in geometrical optics upon which early production and progress in photographic optics was based. Though initially the French opticians had a head start, the English forged into the lead, depending upon modifications or copies of German and French lenses as well as upon their own ingenuity. The collaborations of Petzval and Voigtländer and later Petzval and Dietzler are the only instances of strong influence of science upon lens design during this period. Yet the groundwork laid in the study of glass and optical constants by Fraunhofer and Guinand was not lost upon the practical opticians, especially in Vienna and Paris. Though photographers such as Sutton criticized those using mathematics and science in lens design and production, the initial example of Petzval suggested the mode of success for optical producers during the last third of the century. Increasingly, the role of science became more important, and the leadership of the optical industry shifted from England to Germany.

PHOTOGRAPHIC OPTICS, 1865-1885

In spite of the success of Petzval's designs, English opticians held the lead in photographic optics until the mid 1860's. The English corrected their lenses much sooner for the focal difference of visual and chemical rays than did Voigtländer. By the middle 1860's, however, another instance of close interaction of science, technology, and business signaled the switch in leadership to Germany and established the efficacy of mathematical methods of optical design. The key figures in this new collaboration were two physicists, Carl and Adolph Steinheil, and a mathematician, Ludwig Seidel.

Carl August Steinheil (1801-1870), a well-known German mathematical physicist, possessed a definite practical orientation. Receiving his lower education from private tutors and in schools in Munich, Steinheil attended the Universities of Erlangen, Göttingen, and Königsberg. At Göttingen he worked under Gauss, and then he moved to Königsberg where, in 1825, he received his Ph.D. degree as a student of Bessel. Both of these teachers had worked extensively in mathematical optics. Following graduation, Steinheil engaged in optical calculations and studied the optical works of Fraunhofer. He came to know Fraunhofer, who invited him to join him at his Optisches Institut near Munich. Steinheil declined this offer and in 1827 was named Extraordinary Member of the Munich Academy. He also engaged in the testing of large telescope objectives.

In 1832 the University of Munich appointed him as Ordinary Professor of Physics and Mathematics, a post he held for seventeen years. Following the announcement of the details of the daguerreotype process, Steinheil became interested in photography, though not in any commercial sense. Soon he became very much involved in telegraphy and spent much time in designing telegraph equipment and advising on engineering problems. After spending some time in Switzerland aiding in the establishment of that country's telegraph facilities, he returned in 1852 to Munich. Soon King Maximilian II requested that he try to revive an interest in optics in Munich so that Bavaria might once again hold the position in optics that it had held during Fraunhofer's later years.[34]

As a result of the King's suggestion, Carl Steinheil founded an optical-astronomical workshop in Munich in May of 1855 and devoted himself entirely to the project for the next decade. At first Steinheil confined attention to telescope objectives and employed the techniques initiated by Fraunhofer. He also brought his son Adolph into the business, and this association proved to be important for the later development of the firm and of photography.

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34. Poggendorff, II, 996-998, and III, II, 1288: Eder, pp. 284, 404, and 775; Rohr, Theorie..., pp. 125, 284-286, and 312; Popular Photography, XXXVIII (1956), 120; Willy Kühn, Die photographische Industrie Deutschlands... (Schweidnitz, 1929), p. 30.

Hugo Adolph Steinheil (1832-1893), like his father, took a strong interest in mathematics and physics. He studied at the Universities in Munich, Augsburg, and Vienna. At the latter, where he obtained his Ph.D. degree in 1852, he studied mathematical analysis under the physicist and mathematician, Joseph Petzval. Rohr thinks there was little influence in the field of optics from this contact between these two key figures in the early history of photographic objectives because neither Steinheil nor his father was particularly interested in optics at this time.[35] After graduation, young Steinheil worked with telegraphic problems until his father established the optical workshop, at which time the son joined him in Munich. Gradually, Adolph came into prominence when his name became attached to his father's published works in optics. By 1858 Adolph began calculations on telescope objectives, and the mathematical work of his father, Friedrich W. Bessel, Johann K. F. Gauss, Jean B. Biot, and Joseph Petzval influenced him.[36] In his efforts to design lenses, however, he had to confine his ray-tracing work to paraxial rays because only paraxial rays had been treated in the earlier theoretical works referred to above.

Shortly after the appearance of Petzval's new land-

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35. Rohr, Theorie..., p. 289; Poggendorff, III, II, 1288-1289.

36. Rohr, Theorie..., p. 290.

scape lens in 1857, new inquiry into photographic objectives arose. In England, in particular, opticians and amateurs alike became concerned with developing distortion-free objectives. The Belgian photographer, D. van Monckhoven, one of the leading writers on photographic chemistry and optics of the time, knew Carl Steinheil well and suggested to him requirements for a new objective which, if the conditions could be met, would be far superior to any available at the time. Shortly before, J. H. Dallmeyer in England had produced a triplet which approached Monckhoven's ideal lens, but it fell short in some important areas. Monckhoven made this suggestion to Steinheil because of the success of Steinheil's first photographic objective, the periscope lens, which had appeared in 1865. Voigtländer had recognized this lens as excellent and had obtained a production license from Steinheil.

Soon Adolph Steinheil began calculation of the optics of a photographic lens which would meet the requirements laid down by Monckhoven. Success in this effort to produce the first aplanatic lens[37] came, however, as a result of collaboration with Ludwig Seidel. Ludwig Philipp Seidel (1821-1896), a professor of mathematics, had been active in research in the theory of objectives since 1853. Shortly after Bessel's check of the Königsberg heliometer and

37. Aplanatic has had two meanings historically. John Herschel used the term to refer to an optical system corrected for spherical aberration. Seidel and Steinheil used the term for systems corrected for the spherical aberration and coma.

publication of Gauss's response, which set forth lens formulas based on first-order approximations, Seidel had carried out and published in 1856 a very important investigation of lens aberrations.[38] In this work he set forth his third-order theory of aberrations in which the deviations of rays from an ideal path through a lens are expressed in terms of five sums, called the Seidel sums. Each Seidel sum corresponds to a different type of aberration. Seidel had begun his studies with the investigations of Petzval of 1839 and 1840, in which a small bundle of paraxial rays were considered, but he had gone on to consider bundles of rays striking the lens at an angle to the axis of the lens. In 1865 when Adolph Steinheil began working on Monckhoven's suggestion, he recognized that traditional ray-tracing would not be sufficient and therefore consulted Seidel. Seidel gave him the necessary formulas, and he in turn carried out the calculations for the Steinheil aplanatic lens, the universal quality lens of photographers for the next three decades.[39] Thus mathematical optics became prominent because of the collaboration of scientifically trained personnel such as Seidel and

38. Ludwig Seidel, "Zur Dioptrik. Ueber die Entwicklung der Glieder 3ter Ordnung, welche den Weg eines asserhalb der Ebene der Axe gelegenen Lichtstrahles durch ein System brechender Medien bestimmen," Astronomische Nachrichten, XLIII(1856), 289-332.

39. Rohr, Theorie..., p. 293.

Carl and Adolph Steinheil and the photographer Monckhoven. The Steinheil firm then commercially produced the lens at its shop in Munich.

The aplanatic lens of Steinheil did for landscape photography what the Petzval lens had done for portrait photography. It had a relatively low f number and was corrected for spherical and chromatic aberrations as well as for coma. However, Adolph Steinheil still recognized faults even in this lens and continued to bring improvements to it. In 1881 he sought to eliminate the astigmatism at the edges of the picture with a new antiplanatic lens, which remained popular until the introduction of new lenses utilizing the Jena glasses.[40]

Though Steinheil's introduction of the aplanatic lens shifted German leadership in photographic optics from Voigtländer to Steinheil, the Voigtländer firm continued its active interest in this field. Voigtländer, probably in response to Steinheil's success, initiated mathematical lens design. Friedrich Voigtländer's stepson, Hans Friedrich August Zincke gen. Sommer,[41] actively carried out calculations for the firm. Sommer, who had studied at Göttingen, did not produce any competitive lens systems. Therefore, although Voigtländer remained a strong firm,

40. Eder, p. 405.

41. The name is Hans Friedrich August Zincke gen-(nant) Sommer or Hans Friedrich August Zincke who is surnamed Sommer.

Steinheil gained the leadership position, both in new kinds of lenses and in production of photographic objectives.[42]

At the same time that Germany began to replace England as leader in photographic optics, two photographic journals of importance were founded, the _Photographische Korrespondenz_ and _Photographische Mittheilungen_ in 1864. Though they were founded more than ten years later than the English photographic journals, they soon became important communications media. Unfortunately, they appeared at a time when photographic optics was becoming mathematically too sophisticated for mathematically untrained photographers, and therefore, these journals did not carry significant communications in optical theory and design. Most photographers, as a result, remained unaware of important developments in optics. Hence, these journals did not provide a needed place for optical theorists to publish.[43]

At about the same time that Steinheil developed the aplanatic lens, John H. Dallmeyer in England brought out ~~a similar lens called the rectilinear. A controversy~~ arose over priority between Steinheil and Dallmeyer. Thus, though the Steinheil lens was superior to that of Dallmeyer, Steinheil was unable to patent his lens in England and therefore lost a rich market for his work.[44]

42. Rohr, _Theorie_..., pp. 313-316.

43. The problem was that photographic lens design was too specialized for the physics journals and too mathematical for the photographic journals. Therefore, some of these designs did not get published.

44. _Dict. Nat. Biog._, V, 400-402; Rohr, _Theorie_..., pp. 210 and 218-219; Eder, pp. 404-406.

English amateurs, even in the middle 1860's, continued to publish papers on photographic optics. The English were unique in this regard. The cause may have been the stimulation and opportunity for publication afforded by the Photographic Journal and the British Journal of Photography, founded in 1853 and 1854 respectively. J. Traill Taylor (1827-1895) of Edinburgh, for example, contributed a couple of articles of importance on photographic optics; yet, like so many English amateurs, he remained dedicated to the old school of trial-and-error design.[45] On the other hand, at least one amateur began using mathematical methods for lens design. Robert Henry Bow, a Scottish civil engineer interested in photographic optics as well as in many other scientific matters, as demonstrated by his election to the Vice Presidency of the Royal Society of Edinburgh, did much in Britain to promote mathematical optical design. His influence might have been greater, however, if he had had better connections with practical opticians.[46] During the middle 1860's he contributed a series of articles on optics to the British Journal of Photography, in which he discussed in detail the theory of distortion, astigmatism, and curvature of field.[47]

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45. Rohr, Theorie..., pp. 221-222; Brit. J. Photog., XI(1864), 134-135 and 329-330.

46. Rohr, Theorie..., pp. 200-201.

47. Brit. J. Photog., X(1863), 159-160, 182, 228-231, and 421-422; XIII(1866), 159-160, 256, and 281-283.

After the middle 1860's, however, there seemed to be a decline in interest in optics in England, perhaps due in part to the changing character of lens design and the requirements of mathematics as a base for significant contributions in this field. Changes in the editorship of the two leading English journals may also have influenced interest.

Among commercial opticians interested in photographic optics, J. H. Dallmeyer remained the leader during the period from 1865-1883. The firm of Ross continued under Thomas Ross's direction but did not seriously compete with Dallmeyer. After the death of J. H. Dallmeyer in 1883, the firm of Ross came into more prominence again. Ross obtained the services of Hugo Schroeder, the German optician, whose activities became of great importance at the time of the introduction of Jena glass in 1886.

French and American opticians failed to keep pace with the new advances from Germany and England. During the 1860's J. Zentmayer, a Philadelphia optician, contributed some modifications to Petzval's landscape lens. These modifications became unimportant, however, after the introduction of the improved Steinheil aplanatic lens.[48] Also during this period, John Jacob Bausch and Henry Lomb, German emigrants, founded their optical firm in Rochester, New York. They initially confined their attention to

48. Eder, p. 404.

spectacle and microscope optics.[49]

Late in the 1870's attention became focused upon shutters for cameras. Before this time shutters had been unimportant because the sensitivity of the photo-sensitive surface was low, but with the introduction of the gelatin dry plate, the need for shutters became greater. The air bulb and tube type shutter, working like a trap door, was among the first introduced.[50] Later, large optical firms developed shutters of greater precision. Frequently, optical companies constructed the shutter and built the lens and shutter together in the same tube. Leaders in such production included the Bausch and Lomb Optical Company in the United States, Thornton-Pickard Manufacturing Company in England, and the Friedrich Wilhelm Deckel firm in Germany.

Thus, the implementation of scientific methods of lens design had its impact upon the photo-optical industry in the period 1865 to 1885. The trial-and-error methods originally employed so successfully by the English yielded to the mathematical ray-tracing methods employed by Steinheil and Voigtländer. Since the English opticians

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49. See Blake McKelvey, Rochester, The Quest for Quality, 1890-1925 (Cambridge, 1956), pp. 257-258; William F. Peck, Semi-Centennial History of the City of Rochester, (Syracuse, 1884), p. 638; William F. Peck, History of Rochester and Monroe County, New York... (New York, 1908), p. 426.

50. See articles on shutters in Anthony's Bulletin, X(1879), 265; XI(1880), 119; XII(1881), 291, 352, and 375; XIII(1882), 73 and 102; and XIV(1883), 338.

were unable to make the change at this time, German lens makers became the leaders in quality optical products. It is striking that a similar change occurred at about the same time in microscope lens design. In 1868 Zeiss Optical Company, the leading microscope producer of the world, began production based upon mathematical design. Hence, this scientific approach was first successfully implemented in Germany, where, in contrast to England, France, and the United States, the practical lens designers either hired mathematical physicists, were themselves scientifically trained, or collaborated with academic scientists in order to bring their products to the highest levels of quality possible. This combination of desire for quality and general practical orientation of scientifically trained personnel brought Germany to the front in optical science and production during this period. Once this position was obtained, Germany continued to build on these assets and continued to provide leadership in photographic optics into the twentieth century.

PHOTOGRAPHIC OPTICS, 1885-1900

Two very important advances influenced the development of photographic objectives during the last fifteen years of the century. The first was the striking increase in photographic sensitivity with the introduction of gelatin emulsions. As a result of this increased sensitivity, large-aperture, high-quality objectives were no longer

needed for amateur photographers, the people who soon became the important market for photographic supply manufacturers. Therefore, the large demand for hand cameras brought high demand for simple, inexpensive optical systems. The second advance during this period was the development and commercial production of a number of new optical glasses by Schott at Jena. These glasses allowed new types of lens design by making available for the first time glasses with a variety of optical characteristics. This development further demonstrated the growing importance of science because the new optical characteristics available permitted implementation of mathematical designs previously only theoretically possible. Much of the history of photographic optics at the end of the century is concerned with the use of Jena glass.

The development and introduction of the new glass grew out of the efforts of the Zeiss Optical Company of Jena. This well-established firm started as an optical instrument company in 1846, stimulated in its founding by Jakob Schleiden (1804-1881), the German biologist. Soon Carl Zeiss (1816-1888) made a name for himself in the hand production of microscopes. Although only a practical instrument maker,[51] Zeiss recognized the importance of mathematical optics for lens design and in the middle 1860's, at about the same time as the collaboration between Seidel and Steinheil, employed a physicist, Ernst Abbe (1840-1905). Abbe had studied at the Univer-

51. Auerbach, Zeiss..., p. 5.

sities at Jena and Göttingen, obtaining his degree at Göttingen under Georg F. Riemann and Wilhelm Weber. In 1863 he had become attached to the University of Jena, where he had made a study of error analysis in physics and astronomy. In 1866 he became affiliated with the Carl Zeiss Optical Company while continuing his work at the University. In 1870 the University appointed him Extraordinary Professor; but increasingly his time became devoted to the optical firm,[52] and in 1875 he became a partner in the Zeiss firm. In 1868 the company, due in large part to Abbe's influence, made the change from trial-and-error methods to mathematical methods of lens design and production.[53] However, until the late 1880's, the Zeiss Optical Company confined its attention to production of microscopes.

In the early 1880's, Abbe recognized the serious limitations upon optical designs imposed by the lack of flexibility in optical characteristics of glass. At the time of an exhibition of scientific instruments in London in 1876, he wrote a review of microscopical optics and claimed that nearly perfect lenses could be made if the appropriate glass were available.[54] Abbe's plea fell

52. Ibid., pp. 8-9.

53. Ibid., pp. 8,11, and 268.

54. I have not seen the original of this report although both Auerbach (p. 19) and Rohr (p. 336) refer to Abbe's remarks. Bericht über die wissenschaften Apparate auf des Londoner internationalen Ausstellung im Jahre 1876... herausgeben von A. W. Hoffmann. (Braunschweig, 1878), pp. 383-420.

on deaf ears in Paris, Birmingham, and Manchester, where most optical glass was produced until the late 1880's.[55] In 1882 Otto Schott, a young mineralogical chemist with an interest in glass, settled in Jena and began full-scale collaboration with Abbe on development of new kinds of optical glass.

Otto Schott (1851-1935) studied at the Universities of Aachen, Würzburg, and Leipzig. It was at the latter in 1875 that he obtained his Ph.D., writing a thesis on the defects in the manufacture of window glass. After taking positions in chemical plants in Germany and establishing a glass house in Spain, he moved to Jena. His interest in optical glass came with his discovery of a lithium glass in 1879. He sent a specimen to Abbe, who tested it for optical properties. Though this initial effort was not successful, Schott continued to experiment with new types of glass. In 1881, while Schott still resided in Witten, he and Abbe joined in the study of glass of varying chemical composition. Utilizing the spectrometer, they soon discovered that certain relationships exist between chemical composition and optical properties. This discovery stimulated a systematic investigation of the subject, with Schott moving to Jena.[56]

The results of these studies prompted Schott to establish a glass house in Jena in the fall of 1884. Abbe

55. Kühn, p. 31.

56. Aüerbach, pp. 19-20.

and the Zeiss Optical Company clearly encouraged the establishment of this firm. In addition, however, the Prussian Ministry of Education provided subsidies of about 60,000 marks ($43,000) over a period of two years with the understanding that the glass house was to be moved to Berlin. (Note that the total initial cost was 40,000 marks.)[57] Scientists and technical men, including Abbe, Carl Bamberg, and Wilhelm Förster, aided in gaining this subsidy. The Prussian Minister of Education, von Gossler, a staunch supporter of scientific and technical projects, supported their plea. Even though Schott did not move his operations to Berlin, the subsidy remained in force.[58] Obviously the relationship between Schott and Abbe was too profitable to sever. The issue of the first Jena optical glass catalogue in 1886 inaugurated a new era in optics. Instead of only the crown and flint glass with which opticians normally had to work, many glasses of new composition and characteristics became available.

~~Though Abbe initially intended the new types of glass~~ for improving microscope lenses, gradually photographic

57. Calculation of present dollar value is approximate and based on conversion of marks to dollars from the tables of Encyclopaedia Britannica, 9th ed., American ed., (Chicago, 1892), XVI, 732, and the wholesale price index, 1770-1960, from Committee on Economic Policy, Our National Debt. (New York, 1949): 1 mark = $.238 (1880-1890); 60,000 marks ≙ $14,280; wholesale price index has increased about 3 times since 1880-1890; hence 60,000 marks equals about 40,000 to 45,000 in current dollars. Initial cost then was between $27,000 and $30,000.

58. Auerbach, pp. 20-21; Kühn, p. 33.

optics felt the impact of the new glass. Its availability also indirectly stimulated the founding of the photographic division of Zeiss Optical Company. Nearly as soon as the new glass came on the market, Abbe introduced an improved microscope lens system, the apochromatic lens. He then hoped to use design principles similar to those used in developing the microscope lens to develop an apochromatic photographic objective.[59] Before initiating work on photographic optics, Abbe went to Munich and studied for a time under Steinheil.[60] Then he set one of his assistants, Paul Rudolph, to work on this project in about 1886, but the efforts were a disappointment. Rudolph, who had studied at Munich, Leipzig, and Jena, obtaining his Ph.D. from Jena in 1884, abandoned the design approaches of Seidel and Petzval. He began anew by setting the conditions of a large aperture, no spherical aberration, no astigmatism, no curvature of field, and minimum distortion. Because of the availability of the Jena glass, he could neglect consideration of chromatic aberration and, after removing the other aberrations, utilize the principle of inversely-related refractive indices for front and back parts of the lens system in order to eliminate chromatic aberration. Rudolph successfully produced this new photographic objective in 1890, calling it the anastigmatic lens. Beeause it eliminated four Seidel aberrations and lessened

59. Rohr, Theorie..., pp. 341-342; Auerbach, p. 28.
60. Eder, p. 405.

distortion, this lens excited attention in Germany and throughout the world. Soon Zeiss patented it and then licensed firms in Milan, Vienna, Braunschweig, Basel, Paris, London, and Rochester to produce this lens. It was an extremely important advance in photographic optics and became the basis for many of the modern objectives of Zeiss and other firms.[61] Inasmuch as Zeiss obtained world-wide patents on this lens, in contrast to the limited patents held earlier by Voigtländer and Steinheil on their portrait and aplanatic lenses, Zeiss was the first fully to exploit commercially a photo-optical system designed from scientific principles.[62]

Following the availability of Jena glass, other companies also designed new photographic lenses. For example, in 1886 Adolph Steinheil produced an improved aplanatic lens, while two years later Voigtländer brought out the euryscope lens, a modification of the aplanatic lens employing Jena glass. In 1893 the mathematical optician E. von Hoegh calculated a symmetrical anastigmatic lens system for Goerz Company of Berlin. It became known as both the "double anastigmat" and the "Dagor." That Goerz had produced 30,000 of these lenses by 1896 indicates that they were popular.[63]

61. Rohr, Theorie..., pp. 358-366; Auerbach, pp. 46-47.

62. The earlier Petzval and Steinheil lenses had not been patented throughout the world, and, therefore, their designs were pirated by other optical companies.

63. Kühn, p. 35; Rohr, Theorie..., pp. 354-355; Eder, pp. 408-410.

England did not experience as great an impact from the new glass as did Germany, probably because few people of scientific training were found among personnel of English optical shops. Ross and Company in 1887 produced the first English photographic objective made from the Jena glass, but this was, to a certain extent, a product of German training. Heinrich Ludwig Hugh Schroeder, who was born in Germany and studied at Göttingen under Moritz Meyerstein and J. B. Listing, designed this concentric lens, as it was called. After working in optical shops and unsuccessfully running one of his own, he had emigrated to London, where he had become technical director of the Ross firm. Later, in 1894, he went to the United States, where he worked for a short time for Manhattan Optical Company before returning to London. Publication in 1886 of the Jena glass catalogue stimulated Schroeder to construct his concentric lens. Yet this lens was not available commercially until 1892 because Ross could not obtain the required Jena glass until that time. When the lens was finally in production, the Rudolph anastigmatic lens was already a very strong competitor.[64]

During this time, however, English opticians began to introduce mathematical design, and a few new developments grew out of this movement. Yet, as Reginald S. Clay in a lecture on the history of photographic optics indicated,

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64. Rohr, <u>Theorie</u>..., pp. 345-348; pp. 233-234.

many of the new English designs were actually calculated by Germans such as Schroeder.[65] Exceptions included the work of Thomas Dallmeyer and Harold Dennis Taylor. Thomas Dallmeyer (1859-1906), the son of J. H. Dallmeyer, received a degree (B.Sc.) in mathematics from King's College, London, and began work in his father's firm. He assumed control of the business in 1882 and took part in optical design work, producing the first practical telephoto lens in 1891.[66] Soon other designers, including Adolph Steinheil and Paul Rudolph, also calculated successful telephoto lenses, employing the Jena glass. Taylor, the optical manager of T. Cooke and Sons of York, patented in 1893 an excellent triplet lens, which soon became very popular. Voigtländer even obtained a license and began production of this lens in Germany in 1897. This lens also employed Jena glass.[67]

The history of photographic optics in the period 1885-1900 demonstrates in large part the increasing importance of mathematics and science in the design of lenses and the stimulating effect of Schott-Abbe's development of new kinds of optical glass. By the end of the century, firms which were strongly science-oriented produced most of the quality photographic objectives. Without question, Germany was the

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65. Eder, p. 411; see Optische Rundschau und Photo-optiker, XIII(1923), 907.

66. Brit. J. Photog., LIV(1907), p. 10.

67. Rohr, Theorie..., pp. 237 and 388.

leader in the field, with England holding second position. France and the United States did not play important roles in this period, though there were firms in those countries which licensed and produced the German and English lenses. The relative importance of optics in photography lessened to some extent as the result of increased sensitivity of dry plates and film. Without question by the end of the century the United States was the leading producer in numbers of photographic lenses because of the rise of producers of hand cameras. Yet leadership in quality optics remained in Germany where there was a strong fusion of personnel (1) trained in both theoretical and mathematical optics and (2) experienced in practical optics. Such firms as Steinheil, Zeiss, and Goerz could credit their commercial success to such profitable collaboration.

Chapter V

DEVELOPMENT OF FUNDAMENTAL IDEAS AND INSTRUMENTS IN MEASUREMENT OF LIGHT AND ITS CHEMICAL EFFECT

The sciences of photometry and photography developed hand-in-hand in the nineteenth century. Though studies of photometric problems were conducted long before the practical introduction of photography in 1839, photography helped to stimulate new interest in photochemical problems and provided students in this field with an improved measuring instrument. The classical photochemical studies of Bunsen and Roscoe in the late 1850's and early 1860's concluded with the use of silver chloride photographic paper as a measuring standard. The introduction of gelatin dry plates with their wide variations in sensitivity further stimulated scientific interest in photometry and photographic sensitometry, culminating at the end of the century in the pioneering scientific study of light and its photographic effect by Hurter and Driffield and the modification of the reciprocity law by Schwartzschild.

As in most experimental scientific endeavors, progress in nineteenth century photometrics and photochemistry rested in large part upon the development of new measuring instruments and new analytical procedures. In order to measure the chemical effects of light, chemists and physicists found it necessary to develop standard

(1) sources of light, (2) measures of the intensity of light, (3) measures of the chemical effect of light, and (4) methods of controlling and measuring exposure periods. The development of adequate instruments did not come at once but evolved over the last sixty years of the century. As investigators made improvements in instrumentation, they were able to confirm or reject speculative ideas regarding the laws of photochemistry.

The source of light for photochemical studies was very important. In photometrics, chemists could use a standard source of illumination as long as they knew the intensity of its light; however, in photochemical studies they needed to know the composition of the light itself. Because photo-sensitive materials show variable sensitivity to different wavelengths of light, in order to perform studies which could be precisely duplicated, the investigator had to use a standard source of light. During a large part of the nineteenth century, most observers employed the wax candle, although other artificial illuminating sources came into use. At the beginning of the century, the Carcel lamp was introduced in France, while late in the century the Vernon-Harcourt pentane lamp came into use in Great Britain and the United States. During the 1890's Hurter and Driffield employed petroleum lamps in their investigations. Solar illumination, of course, frequently provided a source of light, but the variable intensity and the

sun's constant motion presented problems in its use.[1]

About the middle of the nineteenth century, Bunsen advanced the measurement of the intensity of light. From the time of publication of Pierre Bouguer's Essai d'optique sur la gradation de la lumière in 1729, natural philosophers recognized that the intensity of illumination is inversely related to the square of the distance, and, therefore, that intensity can be calculated from knowledge of distances of different sources if one can determine when the received intensities of two sources are equal. Early efforts to use this method included those of Ritchie and Count Rumford. The latter employed comparison of shadows.[2] Bunsen's grease-spot photometer, introduced in 1844, proved to be the most successful photometer of the nineteenth century.[3] With this instrument, light from two sources fell on opposite sides of a grease spot on a piece of paper. The paper was placed on a sliding scale and moved until the illumination falling from the two light sources was equal, and thenthe investigator, knowing the distances of the sources from the point of equal illumination, calculated the intensity. Bunsen and Roscoe successfully employed this instrument in their

1. René Taton, ed., Science in the Nineteenth Century, trans. A. J. Pomerans (New York, 1965), p. 145.

2. Count Rumford, "An Inquiry into the Chemical Properties That Have Been Attributed to Light," in his Philosophical Papers, I (1802), 341-365.

3. Henry Enfield Roscoe, The Life and Experiences of Sir Henry Enfield Roscoe (London, 1906), p. 52.

photochemical studies, and, with modifications, Hurter and Driffield also used it with success.

The early investigators encountered many difficulties in measuring the chemical effect of light, but during the nineteenth century they made steady progress. Photography itself played an important role in this area. From the eighteenth century, investigators such as Schulze, Scheele, Senebier, and Ritter employed light-sensitive silver salts for qualitative investigations of the chemical effects of light. With the advent of photography in 1839, photography became important in studies such as those of John Herschel, Eduard Becquerel, and John W. Draper. However, they found that the variability of preparation and sensitivity did not make photography a reliable instrument for quantitative investigations. Therefore, investigators turned to other photochemical reactions for their studies, especially during the middle of the century.

The reaction of hydrogen and chlorine gas became the most important alternative to photography for photochemical studies. John W. Draper (1811-1882) conducted one of the first significant studies of this reaction. Draper was born in England but had emigrated to the United States in 1832. He had earned a medical degree from the University of Pennsylvania and taught physiology and chemistry at New York University. His principal research interests, however, were in the fields of photochemistry, photography, and spectroscopy. Following his

studies of the light sensitivity of daguerreotypes in the early 1840's, he began investigations of the reaction of hydrogen and chlorine gas when exposed to light. For the purpose of measuring the extent of reaction, he produced an instrument which he named a tithonometer. It consisted of a U-shaped tube equipped for electrolysis and measurement of fluid level. After partially filling it with hydrochloric acid saturated with chlorine, he found that some hydrogen and chlorine gas were produced electrolytically in a darkened portion of the tube. Upon exposure to light, these gases combined to form hydrochloric acid, resulting in diminution of the gas which could be measured and taken as an indication of the chemical effect of light.[4]

Bunsen and Roscoe noted defects in Draper's tithonometer and, therefore, designed a substitute instrument. Robert Wilhelm Bunsen (1811-1899), a German chemist, had obtained his doctorate at Göttingen in 1830 and had begun teaching chemistry at the University of Marburg. In 1852 Bunsen had succeeded Gmelin at the University of Heidelberg. Though initially his attention had focused on problems of organic chemistry, by the 1850's his interest had turned to physical chemistry, in

4. John Draper, "Description of the Tithonometer, an Instrument for Measuring the Chemical Force of the Indigo-tithonic Rays," Philosophical Magazine, XXIII (1843), 401-415; for biographical data see The National Cyclopaedia of American Biography (New York, 1893), pp. 406-407.

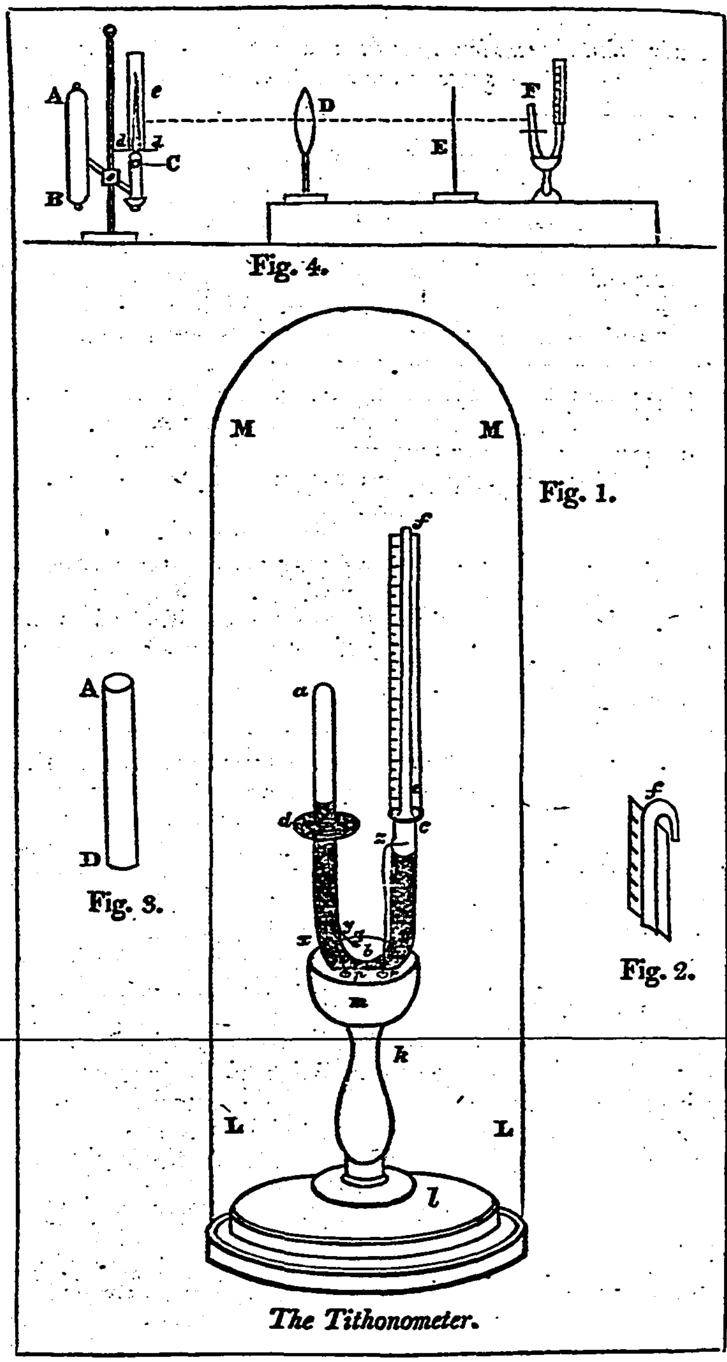

Figure 1. John W. Draper's Tithonometer.

particular to photochemistry and spectroscopy. During the same period that Bunsen collaborated with Kirchoff making the famous discovery of the correlation of chemical composition and spectral line patterns, Bunsen also collaborated with his student, Henry Enfield Roscoe (1833-1915), and, as a result of their work, laid the foundation for quantitative photochemistry.

Roscoe had entered University College in London in 1848 and had become a teaching assistant in chemistry to Alexander Williamson. He had graduated in 1853 and had soon begun studies under Bunsen at Heidelberg. In a short time he had passed his qualifying examination for the doctorate and began his research on quantitative photochemistry. In 1857 he accepted an appointment at Owens College in Manchester but returned to Heidelberg each summer from 1859 to 1862 to continue his investigations with Bunsen.[5]

After reviewing the literature on photochemistry, Roscoe and Bunsen designed a new instrument for measuring the effect of light, an actinometer. When Roscoe had examined the earlier work of Draper, he had noted defects in the design of his tithonometer. Since the pressure in the tithonometer would vary during the experiment, the quantity of chlorine gas dissolved by the liquid would vary; therefore, the composition of the gas did

5. Roscoe, pp. 58-59.

not remain constant. With the actinometer Roscoe kept the pressure constant by having chlorine water on both sides of the gas tube. Both the tithonometer and the actinometer were designed only for studies of light-initiated hydrogen and chlorine gas reactions.[6]

Bunsen and Roscoe also established standards making it possible to use photographic paper as a measure of photochemical effect. They found that the photographic tint is not in direct ratio to the intensity of light. They confirmed that with photographic paper prepared in a standard way equal tints are formed by exposure to light such that the mathematical products of exposure times and light intensities are equal.[7] Abney, Hurter, and Driffield in their later studies also used photographic paper or plates as a measure of photochemical effect.

Late in the eighteenth century Jean Senebier, the French chemist, suggested using established tints for measuring the degree of photo effect. From the earliest

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6. Robert Bunsen and Henry E. Roscoe, "Photo-chemical Researches:
Part I. Measurement of the Chemical Action of Light," Phil. Trans., CXLVII (1857), 355-380;
Part II. Phenomena of Photo-chemical Induction," Ibid., 381-402;
Part III. Optical and Chemical Extinction of the Chemical Rays," Ibid., 601-620;
Part IV. Ibid., CIL (1859), 879-926;
Part V. On the Direct Measurement of the Chemical Action of Sunlight," Ibid., CLIII (1863), 139-160.

7. Bunsen and Roscoe, CLIII, 139-160.

days of photography, paper scale photometers were used.[8] Bunsen and Roscoe, however, provided two important advances. First, they determined the intensity of sunlight as a function of the position of the sun on a daily and yearly basis.[9] This determination became the foundation of photographic exposure tables which photographers successfully used from the 1860's. Second, they established a standard of tint. They needed a black and white shade of fixed color. Therefore, they produced such a color by mixing one part of lamp-black with one thousand parts of oxide of zinc and called the resulting shade the standard tint. Thus, using photographic paper produced in the standard manner, they defined as the unit of measurement of intensity "that intensity of light which in one second of time produces the standard tint of blackness upon the standard paper."[10] Therefore, the photographic process provided a basis of fixed quantitative measure of light intensity.

Bunsen and Roscoe also utilized two kinds of exposure-control instruments. One was a pendulum-controlled shutter which could measure exposure time to hundredths of a second. The other instrument was the sector wheel,

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8. Joseph M. Eder, History of Photography, trans. E. Epstean (New York, 1945), p. 417.

9. Bunsen and Roscoe, Parts IV and V.

10. Bunsen and Roscoe, Part V.

which came into use in the early 1860's.[11] A step scale of exposure on photographic paper could then be made with accuracy. The operator controlled the degree of exposure by the speed and number of revolutions of the wheel. Abney, Hurter and Driffield, and Scheiner also made effective use of the sector wheel in their studies.

With the commercial introduction of gelatin dry plates in the late 1870's and early 1880's, photographers needed a method of measuring sensitivity. In 1881 in England the Photographic Club grew out of the need to choose a standard of sensitivity. This organization adopted and brought into general use the sensitometer of Warnerke. The instrument consisted of a gelatin glass plate divided into twenty-five squares with consecutively increasing opacity. Each square also contained in order of opacity a number between one and twenty-five. The plate whose sensitivity was to be measured was placed behind the sensitometer and exposed under standard conditions. After development, the last number visible upon the plate represented the sensitivity number of that plate.[12]

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11. Bunsen and Roscoe used the sector wheel as early as 1862. Ernst Mach also employed the sector wheel in 1865. See Eder, p. 452. The sector wheel was a specially designed wheel cut so that at differing distances from the axis of rotation differing amounts of the solid wheel were cut away. Therefore, upon rotation and exposure to light a disk of photosensitive paper would receive differing quantities of light depending upon its distance from the axis of rotation.

12. C. E. Kenneth Mees, *The Theory of the Photographic Process* (New York, 1954), p. 774.

Though advances in instrumentation in the nineteenth century contributed significantly to photochemical studies, of at least equal importance were the theoretical ideas, which were either an outgrowth of progress in instrumentation or an important stimulus to construction of new tools. Pierre Bouguer had conducted an early study in photometrics. In his work on light published in 1729, he had pointed out that the intensity of illumination falls off as the inverse square of the distance. Furthermore, he had observed that extinction of light by successive layers of material follows a logarithmic curve. Late in the eighteenth century and early in the nineteenth century, a number of observers noted that photochemical effects are correlated with the intensity of light. For example, H. Benedict de Saussure in 1787 observed that the rate of evolution of oxygen from chlorine water is proportional to the intensity of light. Also Döbereiner noted that hypochlorite decomposes faster in light than in darkness.[13]

During the course of the nineteenth century, the law of reciprocity gradually evolved. In 1839 Faustino J. M. Malaguti (1802-1878), an Italian chemist, accepted the idea that when silver chloride paper is darkened to a certain blackness, the product of the intensity of light and the exposure time equals a constant ($i \times t = \text{constant}$). This professor of chemistry at the Rennes Academy who once

13. J. R. Partington, A History of Chemistry (London, 1964), Vol. IV, pp. 717-718; Taton, p. 144.

worked as an assistant in Gay-Lussac's laboratory did not, however, provide experimental evidence for this proposition.[14] John W. Draper found evidence for this principle in his studies in 1843. Using his tithonometer, Draper found that the quantity of hydrogen and chlorine gas which combines is directly proportional to the time of exposure and the intensity of the light. These observations, however, did not extend over very wide limits of either time or intensity.[15] Later, in 1855, W. C. Wittwer measured the evolution of chlorine from dilute chlorine water due to exposure to light and confirmed that chemical action is directly related to the exposure time and intensity of light.[16] In 1862 Hankel also provided further limited verification of the principle.[17]

Bunsen and Roscoe extended the limits of the reciprocity law in their study completed late in 1862. Using their pendulum-shutter mechanism, standard photographic paper, and direct sunlight, they verified "that equal products of the intensity of the light into the time of insolation correspond, within very wide limits, to equal

14. Annales de chimie et physique, 2nd series, LXII (1836), 5.

15. Draper, pp. 401-415.

16. W. C. Wittwer, "Ueber die Einwirkung des Lichts auf Chlorwasser," Annalen der Physik, XCIV (1855), 597-612. Wittwer was a privatdocent at Munich at the time of this work.

17. Hankel, "Messungen über die Absorption der chemischen Strahlen des Sonnenlichts," Abhandl. d. Kön. Sächs. Gesellschaft der Wissenschaften, IX (1862), 55-90.

shades of darkness produced on chloride-of-silver paper of uniform sensitiveness."[18] In addition, they affirmed the concept of photochemical induction. There had been reports over many years indicating that a certain minimum illumination was required to initiate photochemical reactions. John Dalton in 1809 in studying the reaction of hydrogen and chlorine gas had noted that a period of inactivity followed the initial exposure to light. Similarly, Draper had noted this phenomena in his studies in 1843.[19] Bunsen and Roscoe likewise found that at first there was no union of hydrogen and chlorine, but that gradually activity began and increased to a constant rate.[20] Though Bunsen and Roscoe's studies continued to be influential, twentieth century chemists have found that, as van't Hoff suggested in 1884, the effect was spurious, caused by organic nitrogenous impurities in the water which were destroyed by prolonged reaction with chlorine.[21] In spite of this false lead, the work of Bunsen and Roscoe stands out as the first systematic effort to provide quantitative data on photochemical effects.

Until the early 1880's, photographers did not concern themselves particularly about measurement of sensitivity of

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18. Bunsen and Roscoe, Part V, p. 145.

19. Draper, "On the Interference Spectrum, and the Absorption of the Tithonic Rays," Philosophical Magazine, XXVI (1845) 465-478.

20. Bunsen and Roscoe, Part II.

21. Partington, IV, 723-724.

photographic plates; however, commercial introduction of gelatin dry plates altered this situation. The wet collodion process had provided a relatively uniform sensitivity, but variations in illuminating conditions and quality of chemicals had encouraged rule-of-thumb procedures rather than development of scientific principles. The gelatin dry plate made possible, in contrast to the wet plate, production of plates of uniform sensitivity. In addition, variation in emulsion formulas also made available plates of wide-ranging sensitivities.

With the introduction of gelatin dry plates in the late 1870's and early 1880's, photographers and scientists alike became concerned with the measurement of the sensitivity of photographic plates and accurate determination of exposure times. Even before the advent of the gelatin dry plate, Abney had begun to study the relationship between transparency of the collodion plates and the time of exposure. William de Wiveleslie Abney (1843-1920) was an English photographic chemist and science education official. His science education had consisted primarily of engineering studies with the Royal Engineers. In the early 1870's Abney had been appointed an instructor in the chemistry and photographic departments at the Military Engineering School at Chatham. Later he taught in the science department at South Kensington and became inspector of science schools. Abney possessed a strong interest in the chemistry of the photographic process, introducing

gelatino-citro-chloride emulsion printing paper and hydroquinone as a developer. He also was concerned with spectrum photography and color analysis. He mapped photographically the red and infra-red portions of the solar spectrum, using specially prepared photographic emulsions.[22] During the 1880's Abney extended his investigation of transparency and exposure time to gelatin plates. He produced mathematical curves by relating the step number of the sensitometer with the transparency of the plate. Since extinction is a logarithmic function, these curves are equivalent to curves relating transparency with the logarithm of the exposure time. In 1889 he also suggested that these curves were shaped like the right-hand half of a Gaussian curve. Such a Gaussian curve describes the above phenomena to a limited extent.[23] Also, an astronomer, Pierre Jules César Janssen (1824-1907), in his studies of photography and its use in astronomy noted in 1881 that the photographic effect is not always proportional to the intensity of light.[24]

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22. Dictionary of National Biography, 1912-1921, pp. 1-2.

23. Mees, pp. 163-164; his papers include: "On the Opacity of the Developed Photographic Image," Phil. Mag., XLVIII (1874), 161; "On Measuring Densities of Photographic Deposit with Some Remarks on Sensitometers," Photographic Journal, n.s. XI (1887), 38; "Photography and the Law of Error," Photographic News, XXXIII (1889), 218.

24. Janssen, "Sur la photométrie photographique et son application a l'étude des pouvoirs rayonnants comparés du Soleil et des étoiles," Comptes rendus, XCII (1881), 821-825.

While Abney groped to relate the opacity of a photographic plate with the exposure time, two other Englishmen also began to experiment actively in the same field. These men were the industrial chemists, Hurter and Driffield. The theoretician of the pair was Swiss-born Ferdinand Hurter (1844-1898). He had obtained his lower schooling in Switzerland, majoring in chemistry. After working three years as an apprentice to a dyer at Winterthur, he had begun the study of chemistry at Zurich Polytechnic. In the fall of 1865, upon the recommendation of his major professor, he had gone to Heidelberg, where he had studied under Bunsen, Kirchoff, and Helmholz, receiving his Ph.D. degree "Summa Cum Laude" in 1866. Refusing a professorship at Aarau, he had gone to England, where he had accepted a position as assistant chemist with Gaskell, Deacon, and Company of Widnes. Soon he became chief chemist and continued as chief chemist and technical advisor even after the company merged with United Alkali Company.[25]

At Gaskell, Deacon, and Company, Hurter met Driffield. Vero Charles Driffield (1848-1915) was the experimenter of the pair. He was born in England and educated at the Liverpool Collegiate Schools. Later he had acquired some training in science from a private tutor. At an early age, he had become attracted to photography, and for a year he

25. W. B. Ferguson, ed., A Memorial Volume containing an account of the Photographic Researches of Ferdinand Hurter and Vero C. Driffield... (London, 1920), pp. 4-5.

had worked in a photographic studio. Soon he had become an apprenticed engineer. In 1871 he joined Gaskell, Deacon, and Company as an engineer and became associated with Hurter.[26]

Initially the two men found a mutual interest in music. Meanwhile Driffield continued to devote considerable time to photography. In 1876 he persuaded Hurter to take up photography as a recreation. Hurter, however, disliked rule-of-thumb procedures and the lack of precision in photography at that time. Therefore the two began a joint endeavor to make photography a quantitative science.[27]

In order to estimate correct exposure times, Hurter and Driffield began in the 1880's to study the varying conditions of natural illumination and the sensitivity of dry plates. First, they noted that they not only needed to consider illumination of direct sunlight but diffused sunlight as well. Utilizing the preliminary studies of Bunsen and Roscoe (Hurter having studied under Bunsen), they produced and published exposure tables which listed values of light intensity throughout the entire day and for the whole year. Second, with the general use of the gelatin dry plates with their great variety of speeds, Hurter and Driffield recognized the need to determine accurately relative speeds of dry plates.

26. Ferguson, pp. 5-6.

27. Ferguson, p. 6.

They set to work to try to find a general law expressing the action of light on the sensitive plate and to examine the effect of development.[28] Though Hurter and Driffield published several papers on these topics in the 1880's, their investigations culminated with the classic paper of 1890, "Photochemical Investigations and a New Method of Determination of the Sensitiveness of Photographic Plates."[29]

This six-part study blended both theoretical considerations and experimental verification. The first part introduced several new definitions and defined terms. Hurter and Driffield defined a perfect negative as one in which the opacity of the negative is proportional to the intensity of the light producing it. Transparency and opacity were defined in the usual manner;[30] while Hurter and Driffield defined density of a negative as the number of particles of a substance spread over a unit area

28. Ferguson, pp. 6-32.

29. This paper was published in the Journal of the Chemistry Industry (Vol. IX, #5). In examining this paper, I have used the reprint available in the Ferguson volume.

30. Transparency = $\frac{I_x}{I}$ which may be expressed as ϵ^{-kA}

where I_x = intensity of a light passed after passing A molecules of the substance
I = intensity of the incident light
k = coefficient of absorption for that material

Opacity = $\frac{1}{T} = \frac{I}{I_x} = \epsilon^{kA}$

multiplied by the coefficient of absorption. Hence the density equals the logarithm of the opacity. Thus, in a perfect negative the density $\doteqdot$ ln KIt.[31] Such a concept was consistent with the reciprocity law as developed during the nineteenth century. In the next two parts Hurter and Driffield described their photometer and their investigation of photographic development. Utilizing experimental data as well as theoretical considerations, they demonstrated that the ratio of different densities of an exposed negative is independent of the time of development. In the fifth part, they reported their measurement of the density of negatives exposed for various periods and found that, in general, density is not a linear function of the logarithm of the exposure time. Therefore, they concluded that a perfect negative could not be acquired for all exposure times; however, within certain limits the function is linear (that is, truly a logarithmic function of the exposure time), and, therefore, they suggested that by adjusting the time to the intensity of light, one could make the exposure fall within what they called the "period of correct representation." In the course of this report they also noted that with thinly coated plates the linear portion of

31. Density = k A; $T = \epsilon^{-kA}$ $\mathcal{T} = \epsilon^{-D}$ $O = \epsilon^{kA} = \epsilon^{D}$
Therefore, $D = \ln O = -\ln T$.
Since in a theoretically perfect negative $O \propto It$,
$D = \ln O \propto \ln It$ or $D = \ln kIt$. See the paper, Ferguson, pp. 77-78.

the function is shorter than with thickly coated plates.[32] Finally, they introduced a method of determining the speed of plates. Defining the inertia of a plate as the least exposure which will just mark the beginning of the period of correct representation (which corresponds to the intersection of the exposure axis and the slope of the linear portion of the function), they observed that this quantity is a reasonable measure of relative speed and characteristic of the particular emulsion used.[33]

In this paper Hurter and Driffield brought together the concepts, data, and instruments employed by earlier photochemists and photographers such as Bunsen, Roscoe, and Abney. But, equally important, they employed a fresh approach with the introduction of the new concepts of density and inertia. This paper may be said to have laid the foundation for the quantitative study of the photographic process.

At first the paper did not arouse any particular enthusiasm. In March of 1890 Hurter read a paper very similar to the classic paper before the Photographic Society of Liverpool University College.[34] Hurter presented the classic paper itself to the Liverpool Section of the Society of the Chemical Industry in late

32. Ferguson, p. 114.

33. Ferguson, pp. 115-121.

34. "On Recent Photophysical and Photochemical Researches," read by Hurter March 17, 1890, to the Photographic Society of Liverpool University College. This paper is reproduced in the Ferguson volume.

May, and the paper was published in The Journal of the Society of Chemical Industry. Driffield later commented that perhaps the reason for the lack of enthusiasm for the paper was Hurter's extensive use of mathematics.[35] The first professional response to the paper was critical. Two knowledgeable photochemists and photographers, W. de W. Abney and Chapman Jones, criticized the photometer used by Hurter and Driffield and also raised questions about certain unclear points. In the long run, Hurter and Driffield's response to these objections helped to clarify the concepts presented in the paper and thereby enhanced its usefulness.[36] Since 1890 other investigators have built on this foundation, but the foundation itself has withstood the test of time.

The end of the nineteenth century and the beginning of the twentieth century witnessed substantial revision in the thinking of photochemists. In 1900 the astronomer Karl Schwartzschild (1873-1916) in conducting stellar photographic studies further generalized the reciprocity law.[37] The photoelectric studies of Einstein, Lenard, and Hallwach combined with the statistical techniques from

35. Photo-Miniature, V (1903), p. 337. Note that pp. 337-397 give a good qualitative discussion of the matter written by Driffield in 1903.

36. Photog. J., LXXXIV (1944), p. 129.

37. $E = I\,t^p$ where p is characteristic of the photosensitive substance. See Photog. Korresp. XXXVI (1899) and J. C. Poggendorff, Biographisch-Literarisches Handwortenbuch zur Geschichte der exacten Wissenschaften (Leipzig, 1926), V, 1143-1144.

thermodynamics, electricity, and magnetism employed by Gibbs and Maxwell aided in Max Plank's formulations of quantum concepts at the turn of the century. The classical view of light and matter and their interaction slowly crumbled before mounting evidence in support of quantum ideas. Though the new concepts did not immediately affect the photographer or the photographic industry, the problems of the new century soon commanded the attention of scientists working in photochemistry and photography.

In conclusion, the photochemical ideas developed by chemists and photographers during the last half of the nineteenth century did influence the photographer and the industry. Bunsen and Roscoe's work was soon translated into practical exposure tables for wet collodion photographers. Hurter and Driffield made improvements upon these and correlated them with sensitivity scale readings for gelatin emulsions. Before the end of the century, they also had patented their actinograph and marketed it in England. At about the same time in Germany, an astronomer, Dr. Julius Scheiner, developed a sensitivity scale which competed with that of Hurter and Driffield. Both scales were in use by the end of the century, with most companies eventually marking their plates and films with these sensitivity numbers.[38]

38. Photog. Korresp., XXXVII (1900), 170-171, lists English firms using Hurter and Driffield (referred to as H & D) sensitivity numbers: Marion, Cadett, and Neall. and Imperial Dry Plate Company. The Eastman Kodak Company provided Warnerke sensitometer numbers; see also Mees, pp. 775-776.

Thus, the foundation for standardization was laid. Again, as in other cases, the turning point in the quantification of photography came with the introduction of the gelatin dry plate. Though the studies of Bunsen and Roscoe came during the popular period of the wet collodion process, their work was academic and not oriented toward the practical problems of photography. It just happened that some of their work was relevant. The influence of Bunsen on Hurter and of the studies of Bunsen and Roscoe on Hurter and Driffield cannot be measured, but that such an influence existed is evidenced by frequent references to their work. The studies of the industrial chemists, Hurter and Driffield, however, were not academic but were highly practical, oriented toward solving specific problems in photography. Thus, when the new gelatin plates presented an array of new practical problems, the most significant attacks on these came from academically trained scientists who were faced with practical photographic problems, the astronomers like Janssen, Scheiner, and Schwartzschild, and the theoretical chemist Hurter, who was brought to photography by the practical laboratory man, Driffield. Yet, without the possibility of standard factory production of negative materials, the practical and commercial relevance of the findings would have been considerably less than it was.

PART II

Chapter VI

PHOTOGRAPHIC MATERIALS INDUSTRY

During the sixty-year period from the commercial introduction of photography until the end of the nineteenth century, four distinct changes in photographic technology occurred. These changes, in turn, affected the character and structure of photographic materials production.[1] From 1839 until the middle 1850's, the daguerreotype process was the most common photographic process in use. A few daguerreotype manufacturers appeared, particularly in France and the United States, where the process was most popular. The French producers furnished materials for the German market and for a limited English market as well as for their own. These producers, with the exception of one company in the United States, remained relatively small and did not stay in business during the following stages of technological change.

When the daguerreotype process was superseded by the wet collodion process, photosensitive materials for use in cameras could no longer be produced in factories for later use by the photographer. Therefore, the number of producers of photographic materials declined sharply from 1855 until 1880, with only a few firms manufacturing

1. "Photographic materials" is used here in a limited sense which does not include printing paper but only those sensitive materials used directly in a camera.

special items such as tintypes, dry collodion plates, or specialized photographic chemicals.

With the introduction of gelatin emulsions in England in the early 1870's, a revolution in photography began. The gelatin emulsions made possible once again factory production of photo-sensitive materials for use in cameras. Moreover, the increased speed of gelatin emulsions over wet collodion plates made inexpensive hand cameras practical because the speed was great enough that (1) the camera no longer needed to be placed on a tripod and (2) simple, inexpensive optical systems were adequate for bringing sufficient light to the sensitive surface. Therefore, not only did the introduction of gelatin dry plates bring the return of factory production of photographic materials, but it also brought to photography the amateurs, who previously were unable to take photographs because of the complicated operations of the wet collodion process. Hence, the general level of activity in photography and photographic materials production rose sharply after 1880.

The introduction about 1890 of celluloid film, which replaced the glass plates, brought an even more substantial increase in the number of amateur photographers. As a consequence of this increase, production of both photographic materials and apparatus became a big business, with mass production carried on in large factories.

Throughout the period from 1839 to 1890, most

producers, with the exception of those in Germany, did not come from scientific backgrounds or have close ties with scientists; however, with the development of large businesses and increasingly competitive pressures during the last decade of the century, employment of chemists and the establishment of company research facilities became more common.

DAGUERREOTYPE

Because the Frenchman Daguerre developed the first commercially successful photographic process, it is not surprising that France became the photographic center of the world during the first decade after the introduction of the daguerreotype process. Though the camera and vapor boxes were necessary for daguerreotypy, the copper-silver daguerreotype plates became the most important industrial items. During the early years of commercial photography, most practitioners depended upon their local apothecaries for chemical supplies; but by the middle 1850's photographic supply houses became the principal retail distributors in Western Europe and the United States.

Patent and licensing restrictions on both the daguerreotype and the paper photography processes developed at about the same time by Herschel and Talbot retarded interest in either process in England. In the German-speaking countries when many people became interested

in photography, photographers depended upon French companies for supplies. The United States was second to France in the general popularity of the new daguerrectype because the distance from French suppliers permitted the growth of an independent industry in the United States.

During the first decade and a half of commercial photography, Paris was the world's daguerreotype supply center. Initially, photography enlisted enthusiastic interest in France, and this enthusiasm prompted substantial demand for daguerreotype plates. Alexis Gaudin, the editor of La Lumière, the early French photographic journal, entered upon production of silver-copper plates as one of the earlier manufacturers. Gaudin produced in Paris a series of plates of varying quality which depended upon the thickness of the silver coating. These plates were marketed under the trademark of a star, a symbol of quality to photographers all over the world.[2] In the early 1850's when the daguerreotype was at the heighth of its popularity, Paris had eight producers of plates. Three of these manufacturers counted for most of the plates. The largest producer, Gaudin, made about 55 per cent of all French plates.[3] In addition to those producing only plates in Paris, in 1856 more than one hundred establishments devoted themselves to the general production of photographic

2. Humphrey's Journal, VII (December 15, 1855), ad, page 10.

3. Ibid., IV (1852), 239 (reprint of an article from the French journal, La Lumière).

materials such as daguerreotype cases, head stands, portrait stools, scenery, and other studio accessories. These Parisian establishments not only supplied French photographers with needed materials and apparatus but also exported goods to Germany and, to a lesser extent, to England and the United States.[4]

In the German-speaking countries, the announcement of the daguerreotype process elicited considerable enthusiasm. Gold- and silversmiths in the larger metropolitan areas such as Berlin and Vienna produced daguerreotype plates on a limited scale. Most German photographers, however, depended upon the large French manufacturers for plates.

The commercial circumstances in England differed from those elsewhere. Initially, Daguerre granted Giroux an exclusive license for production of daguerreotype equipment; however, the contract specifically excepted England.[6] Daguerre patented the process in England through his English patent agent, Miles Berry, prior to announcement of the details in France. Therefore, in order to practice daguerreotypy or to produce commercially materials for the process, photographers and manufacturers were required to pay substantial fees to Berry. Likewise,

4. Ibid., VII (1856), 328.

5. Eder, History..., pp. 281-282 and 285. See also Wilhelm Dost and Erich Stenger, Die Daguerreotypie in Berlin 1839 bis 1860... (Berlin, 1922).

6. See original Giroux contract reprinted in appendix of Gernsheim, Daguerre....

William Henry Fox Talbot held four patents by which he controlled paper photography in England. He also required payments of license fees by commercial practitioners of the calotype process. The patents of Berry and Talbot imposed a serious limitation upon the commercial exploitation of photography in England until the middle 1850's.[7]

In spite of restraints upon commercial photography and production of supplies, a few producers did appear in England. A chemist by the name of Robinson produced the first commercial daguerreotype plates in September, 1839, but had to cease activities for failure to possess the required license. In 1840 Claudet and Houghton held the only license on the daguerreotype process in England. They produced daguerreotype supplies, laying the foundation for a photographic supply house which remained in business through the rest of the nineteenth century. In 1841 Richard Beard, an English studio photographer, purchased the daguerreotype patent from Berry and proceeded to make a fortune during the remainder of the decade from his studio and sale of licenses. However, the demand for daguerreotype supplies was not sufficient to encourage large-scale production of plates or accessories. Photographic interest in England did not move out of the doldrums until the early 1850's, when Talbot partially

7. Gernsheim, History..., pp. 85-88, 132-134, and 142; and Daguerre..., p. 157.

relaxed the enforcement of his patents; however, daguerreotypy never did become a popular process on English soil. Therefore, those who practiced it in England, like those in Germany, depended upon French producers for quality materials.[8]

The daguerreotype process was very popular in the United States from 1839 until the middle 1850's; and, as a result, a number of companies undertook production of plates and accessories. Samuel F. B. Morse encouraged the Scovill Manufacturing Company, one of the earliest producers of plates, to begin their manufacture. Morse had journeyed to France to handle matters concerned with his telegraph. While in Paris, he had learned of the daguerreotype process from Daguerre and had returned to New York with enthusiasm for the new process. After many successful experiments, Morse encouraged the Scovills to enter upon the manufacture of silver plates, arguing, "There will be such a demand for them soon, that they will be used like paper."[9] The Scovill Manufacturing Company of Waterbury, Connecticut, had a long history of metal fabrication and was recognized as an established brass and gilt button producer. The experience of the company in purchasing and working with copper put it in a good position to produce the copper-silver daguerreotype plates. In 1842, therefore, the company began

8. Photographic News, XLIII (1899), 686, and Gernsheim, Daguerre..., pp. 141 and 151.

9. British Journal of Photography, XVIII (1871), 530-532 and 582-583.

production of daguerreotype plates and soon became not only the largest producer in the United States but one of the leading producers of the world. The two principal owners, the brothers J. M. L. and William H. Scovill, used copper from Great Britain rather than from American sources because it was more perfectly refined and, therefore, produced more even surfaces for daguerreotypes. They prepared the plates by means of a rolling operation in which they plated the silver upon the copper and then cut the plates to the required sizes. The Scovill plates obtained a favorable reception in the market place, and by 1845 the company furnished the entire American supply of plates. In the 1850's it extended operations to manufacture daguerreotype cases, head rests, and similar metal accessories. From 1849 the Scovill brothers had jointly operated with Samuel Peck a daguerreotype case plant in New Haven, Connecticut. During the early 1850's the demand grew so substantially that they enlarged production facilities and employed as many as 150 men.[10]

The Scovill company also operated a supply house in New York City, the New York Daguerreotype Stock Depot.

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10. Chauncey M. Depew, ed, 1795-1895 One Hundred Years of American Commerce (New York, 1895), Vol. II, p. 652; Edward E. Atwater, History of the City of New Haven, Connecticut. (New York, 1887), p. 625; John Leander Bishop, A History of American Manufactures from 1608-1860..., 3rd ed. (Philadelphia, 1868), Vol. I, pp. 440-441; Joseph Anderson, ed., The Town and City of Waterbury, Connecticut... (New Haven, 1896), Vol. II, pp. 277-278 and Vol. III, p. 1041; and Humphrey's Journal, IV (1852), 255, and VI (1854), 25.

It offered both foreign and domestic photographic supplies. Even though Scovill was the leading American plate producer, the New York Depot featured French plates, in particular those of Gaudin.[11]

Another large daguerreotype supply manufacturer, the company of William and W. H. Lewis, established what was reputed to be "the largest manufactory for Daguerreotype apparatus in the world"[12] at Daguerreville, a small village near Newburgh, New York. This firm specialized in cameras and accessories and did not concentrate upon plate production. During the early 1850's the company changed ownership several times and apparently ceased operations after the middle 1850's. The decline in popularity of daguerreotypes at that time may have brought the demise of the firm.[13]

The company of Holmes, Booth and Haydens in Waterbury, Connecticut, began production of daguerreotype plates in 1853. In that year Henry H. Hayden went to Paris seeking a man to supervise the making of plates. He brought back to the United States August Brassart, who in 1838 had been employed by Daguerre to make his first plate. Brassart continued to work for Holmes, Booth, and

11. Daguerreian Journal, I (1851), 190; and Humphrey's Journal, VII (January 15, 1856), ad page 8; VII (1855), 6; VII (July 15, 1855) ad page 4; and VII (1856), 297.

12. Daguerreian Journal, III (1851), 20.

13. Daguerreian Journal, II (1851), 370; III (1851), 20; and IV (1852), 11-12; and Humphrey's Journal, IV (1852), 28; IV(1853), 287; and V (1854), 302.

Haydens until 1857, when tintype photography superseded the daguerreotype process. Concurrent with the establishment of the factory in Connecticut, the company also opened a supply house a short distance from that of Scovill in New York. In the late 1850's Holmes, Booth and Haydens produced some tintype materials but concentrated on retailing in New York. At the end of the Civil War, the company retired from the photographic business.[14]

In 1847 Edward Anthony (1816-1888) founded a photographic supply company of importance during the daguerreotype era in the United States, the Anthony Company. He had graduated from Columbia College in New York with a degree in Civil Engineering. Soon after the introduction of photography in the United States, Anthony had taken daguerreotype lessons from Samuel F. B. Morse and then had left New York with Professor James Renwick, one of Anthony's former instructors, to survey the northeastern boundary of the United States for the State Department. Anthony had taken photographic equipment with him on the trip and had made practical use of it in the survey work. Renwick had submitted their report for consideration in negotiations for the Webster-Ashburton Treaty between the United States and Great Britain. After his return to New York, Anthony and J. M. Edwards, with the backing of Dr. J. W. Chilton, a physician and chemist, had started

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14. J. Anderson, Vol. II, p. 352, and Vol. III, pp. 1041-1042; and Humphrey's Journal, V (1853), 202; VII (1855), 2; and XVII (1865), 222.

a daguerreotype gallery in New York. In 1847 Anthony established a supply house and factory for the production of photographic goods. As business expanded, Edward brought his brother, Henry T. Anthony, into the business, and in 1852 they organized the E. and H. T. Anthony and Company, producing photographic paper, apparatus, and chemicals. They located the chemical plant in Jersey City, where it remained in operation for 52 years before being moved to Binghampton.[15]

Smaller companies which were located in various metropolitan centers also produced daguerreotype plates and supplies. In Chicago in the middle 1850's more than fifty men worked in the production of daguerreotype and tintype plates.[16] In Philadelphia in the 1850's the firms of Germon and Broadvent produced plates, and a number of companies manufactured daguerreotype cases. Philadelphia, the center of the American chemical industry at the time, supplied a substantial portion of photographic chemicals. The two largest producers of such chemicals, Garrigues and Magee and Benjamin J. Crew and Company, supplied

15. Chauncey M. Depew, Vol. II, p. 652; L. R. Hamersly, *Who's Who in New York City and State* (New York, 1905), p. 24; William Haynes, *American Chemical Industry* (New York, 1949), Vol. VI, p. 176; *Prominent Families of New York*... (New York, 1897), p. 22; William Foote Seward, ed., *Binghampton and Broome County, New York, A History* (New York, 1924), Vol II; and Robert Taft, *Photography and the American Scene* (New York, 1964), pp. 52-54.

16. *Fourth Annual Review of Commerce, Manufactures*,... (Chicago, 1856), p. 49; For 1855: Daguerreotypes and ambrotypes: Capital, $43,500; Hands, 47; and Value, $70,000. *Sixth Annual Review of Commerce, Manufactures*..., (Chicago, 1858), p. 47: For 1857: Capital, $75,000; Hands, 75; and Value, $100,000.

silver nitrate, gold chloride, collodion, sodium thiosulfate, and acids. The company of Andrews and Thompson, established in Baltimore in 1853, competed with these firms, producing silver nitrate and gold chloride.[17] Philadelphia also was the home of the Langenheim brothers. W. and F. Langenehеim, born in Germany, had moved to Philadelphia in the 1840's, where they had operated a daguerreotype studio. In 1846 they had imported projection apparatus and slides from Vienna and begun production of slides utilizing Niepce's albumen process.[18] In New York City, the photographic trade center for the first two decades of commercial photography, several small companies produced photographic materials. These included L. Chapman, John Roach, and Mathew Brady. Brady (1823-1896), a pupil of Samuel F. B. Morse, produced daguerreotype cases for a short time before opening his New York gallery in 1844.[19]

Thus, as a result of the popularity of the daguerreotype process in the United States, a number of manufacturing concerns developed. The two major supply companies of the nineteenth century, Scovill and Anthony, initiated production during this period. The time of entry, however, seemed to influence to some extent the potential for survival in the photographic business. Both Scovill and Anthony

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17. Edwin T. Freedley, Philadelphia and its Manufactures... in 1857, (Philadelphia, 1858), pp. 209-211, 421, and 466.

18. British Journal of Photography, 12(1865), 318.

19. Daguerreian Journal, II (1851), 212-214, and IV (1852), 12.

entered early upon photographic material production, and they survived the technological change from the daguerreotype to wet collodion photography which occurred between 1855 and 1865. Other companies, such as Lewis and Holmes, Booth, and Haydens, which entered later, did not successfully make the change. Smaller firms such as Germon and Broadbent also encountered difficulty. The major companies -- Anthony, Scovill, and the Philadelphia chemical houses -- apparently possessed sufficient capital to make the change to collodion photography and sufficient good-will with their customers to insure a market when the change occurred.

The change brought with it a decline in opportunity for factory production of photographic materials. Companies produced printing paper in factories, but its value did not compare to that of the metallic daguerreotypes. The chemical companies supplied the photographer with the chemicals requisite for making the collodion coatings, and the established glass companies supplied the plate glass, but the photographer had to prepare from these supplies his own wet collodion plate just prior to taking the picture. Thus, factory production of wet collodion plates was not feasible.

Therefore, some companies failed to survive during the change in technology, and few new entrants appeared, with the exception of small companies in towns of the expanding West. None of the American companies, either

the old or new, possessed any close connection with scientifically trained personnel, and, therefore, no specific influence may be attributed to science in the early development of these American companies.

COLLODION PLATES AND TINTYPES

From the late 1850's until the late 1870's, the wet collodion process dominated photography in France, Germany, England, and the United States. In contrast to the daguerreotype process, the collodion process did not permit factory production of the photosensitive materials which the photographer placed in his camera. In addition, photographers found that the process was more difficult to practice than daguerreotypy, and, therefore, large numbers of people were not attracted to photography. As a consequence, with the exception of photographic paper manufacture, factory production of photographic materials declined during this period.

A few processes appeared, however, which did lend themselves to factory preparation. Yet the two principal ones, the dry collodion and tintype processes, did not encourage the founding of important companies.

Dr. Richard Hill Norris of Birmingham, England, introduced collodion dry plates in 1856 and continued production for about ten years. About 1865 he encountered stiff competition from Bolton and Sayce of Liverpool. Throughout the collodion period such plates were available, but they were not widely used because they possessed about half the speed

of wet collodion plates.[20]

In the United States the tintype became very popular in the decade 1855-1865. The tintype was a collodion photograph on a thin, smooth sheet of iron instead of a negative on glass. It revealed the positive image by reflected light in contrast to the negative image revealed by transmitted light with a collodion-on-glass photograph. Hamilton L. Smith, Professor of Natural Sciences at Kenyon College in Ohio, developed and patented the process in 1856 and sold patent rights to a former student, Peter Neff, Jr. Soon Neff and another student of Smith, Victor M. Griswold, began production in Ohio and became stiff competitors of each other. Griswold gained the advantage competitively by using thinner plates. In the early 1860's Neff went out of business, and Griswold moved operations to Peekskill, New York. The process became popular in the early 1860's, and other producers began to appear, making competition very keen. The Scovill Manufacturing Company entered upon production and soon became the leading producer. After the Civil War, Griswold ceased production when the popularity of tintypes began to wane. The cheap tintype never did command the respect of high-quality photographers and did not become

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20. Gernsheim, <u>History</u>..., pp. 258-260, discusses the work of Dr. Richard Hill Norris and his dry plate production. He does not, however, indicate the sources of his information. That Norris manufactured collodion dry plates and sold them in all the larger cities of England is reported in <u>Cassells Cyclopaedia of Photography</u> (New York, 1912), Vol. I, p. 199.

popular in Europe until the end of the century.[21]

The wet collodion period was not a period of entry of vigorous new enterprises. The older established firms in France and the United States retained a position by acting as retailing houses for photographic supplies. In England the old firm of Houghton likewise maintained its position as a supply distributor, but production on a large scale became confined basically to photographic paper. In contrast to the first decade of commercial photography, scientists and scientific societies tended to lose their interest in the chemical aspects of photography, and professional photographers lost some important contacts with scientists by forming their own organizations and publishing their periodicals. From 1850 experiments had been conducted with gelatin as a binding agent, but it took more than twenty years before photographers fortuitously discovered the increased sensitivity of gelatin silver halide emulsions, which laid the foundation for the growth of amateur photography and the establishment of large-scale industrial production.

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21. Taft, pp. 153-164; Bishop, Vol. I, p. 441; Anderson, Vol. III, p. 1042; and also see E. M. Estebrooke, The Ferrotype and How to Make It (Cincinnati, 1872), Chapter 6.

DRY PLATE

Great Britain

During the early 1870's English amateurs such as Dr. Maddox and John Burgess conducted experiments with gelatin silver bromide emulsions and found them to be reasonably good substitutes for wet collodion plates. Burgess advertised for sale gelatin emulsions which were to be poured on glass plates. His efforts did not, however, result in commercial success because of defects in the surface of the dried emulsion due to soluble crystalline salts. In late 1873 J. King and J. Johnston reported in the British Journal of Photography that these crystalline salts were water soluble and could be removed. Another English amateur, Richard Kennett (1817-1896), patented in November of 1873 gelatin pellicles which, when soaked in water and heated, dissolved and could then be poured on glass plates. In March of 1874 Kennett began commercial production of both gelatin pellicles and prepared plates.[22]

These plates were not very popular at first. John Werge, a salesman for Kennett's plates in the middle 1870's, claimed that professional photographers were too conservative and that many would not even try the new gelatin plates.

22. British Journal of Photography, XX (1873), 348; Gernsheim, History.., pp. 263-264; Kennett's patent: #3782; see British Journal of Photography, XXI (1874), 291.

Those photographers that did use them encountered difficulties with them because they were so much faster than collodion plates and, therefore, required special handling in order to avoid fogging. In the late 1870's, however, amateur photographers began testing and adopting gelatin plates, and soon the professionals gave them come consideration.[23]

The demand for the new and highly sensitive gelatin dry plates began to stimulate the establishment of a number of small factories for their production. The leading firms were the Liverpool Dry Plate Company, Wratten and Wainwright, Mawson and Swan, B. J. Edwards, and Samuel Fry and Company. By the fall of 1879 there were at least fourteen gelatin dry plate manufacturers in Great Britain.[24]

Early in 1876 the Liverpool Dry Plate and Photographic Printing Company had added production of gelatin dry plates to their manufacture of collodion dry plates.[25] About 1878 the Liverpool firm transferred production and offices to London, where gelatin dry plates and collodion

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23. Werge, Evolution..., pp. 95-97.

24. Werge, Evolution..., pp. 96-97; Ackerman, p. 26; and Gernsheim, History..., p. 226.

25. It seems likely that this company is a continuation of the firm which out-competed the Norris Dry Plate firm in the late 1860's; however, Gernsheim, History..., pp. 284-285 and 259-260, gives conflicting details regarding the origin of the firm. No sources are cited, and there is no method of determining the origin with accuracy. Eder, History..., p. 425, also claims that the firm was established in 1874 by Peter Mawdsley.

emulsions were produced. The firm terminated activities in 1884.

F. C. L. Wratten (1846-1926) had established the photographic firm of Wratten and Wainwright in 1876 and in early 1877 had begun production of gelatin bromide dry plates. Wratten continued to experiment with his emulsion and to increase the sensitivity of his plates. Soon the firm had a strong market not only in London and Great Britain but all over the continent, including in Berlin and Vienna. The firm remained relatively small throughout the century but concentrated upon quality and the improvement of its products. Early in the twentieth century Dr. C. E. Kenneth Mees (1882-1960) joined the firm as joint managing director. Mees had studied physics and chemistry at the University of London, where he obtained a Sc. D. degree in 1906. While at Wratten and Wainwright Mees brougnt his colleague, Dr. Samuel E. Sheppard, into the small company laboratory where together they carried out extensive scientific investigations in photography, many of which showed the influence of Hurter and Driffield's work.[26] The Eastman Kodak Company purchased the firm in 1912 in order to acquire the services of Mees and Sheppard for its newly expanded research laboratory in Rochester, New York.[27]

26. See their early work: S. E. Sheppard and C. E. Kenneth Mees, Investigations on the Theory of the Photographic Process (London, 1907).

27. Werge, Evolution..., p. 101; Photographic News, XLV (1901), ix; British Journal of Photography, LIV (1907),

Another important figure in the development of the dry plate industry in England was Joseph Swan (1828-1914). Swan, called the English Thomas Edison because of his interests in electricity and lighting, obtained little formal education. Yet from an early age he took an interest in chemistry and electricity. In 1842 he became an apprentice to a druggist and in 1846 took a job as chemist and druggist with a family friend, John Mawson, at Newcastle. During this period he studied the new literature on photography. Through Mawson he gained access to the <u>Philosophical Magazine</u> and other scientific and technical literature. Schönbein's discovery of guncotton attracted Swan's attention in the late 1840's, and he carried out many experiments with guncotton and collodion. He developed his own formula for making collodion, and between 1852 and 1856 he and Mawson began commercial production of it. Soon their firm became one of the leading English producers for photographers. At this time Swan was admitted to the firm as a partner, and the name became Mawson and Swan. From 1856 to 1866 Swan conducted many photographic experiments, some of which led to his development of a carbon process, which was used by the Autotype Company. Thomas Barclay, who later became an important chemical manufacturer at Birmingham, assisted Swan in these investigations.[28]

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430 and 567; <u>Photographic Journal</u>, LXXXIV (1944), 305; Wentzel, p. 6; Ackerman, pp. 240-241; and Eder, <u>History</u>..., p. 778 (footnotes).

28. Swan, pp. 21-22, 26-27, 29-30, 34, and 39; Werge, p. 40; and <u>Photographic Journal</u>, XIV (1869), ii.

During the 1870's the firm of Mawson and Swan continued to manufacture chemicals such as collodion, but it also produced scientific instruments and collodion dry plates. With attention in the middle 1870's focusing upon the new gelatin process, Swan learned of the gelatin emulsions and in 1877 began investigations to remove some of the problems of the gelatin process. By the end of the year he was producing in his laboratory, gelatin plates which rivaled the speed and quality of collodion plates. Soon he observed that variations in sensitivity of dry plates were due to temperature differences in the preparation of the emulsion. He therefore discovered the ripening process and used it effectively in his production of plates; however, he retained this important information as a trade secret, hoping to gain an advantage over other gelatin plate manufacturers. In 1878 the company of Mawson and Swan built a special factory for production of plates, and soon Swan's plates were in demand all over England as well as abroad. In 1879 Swan patented an automatic glass-coating machine which made possible more uniform coatings and faster production. At this time Swan became very much interested in making a practical incandescent lamp, and for the next decade or so his attention was directed more toward electrical experiments and production than toward photography.[29]

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29. Gernsheim, History..., p. 266, and Swan, pp. 43, 49, and 55.

Mawson and Swan continued to produce gelatin dry plates throughout the remainder of the century, though the firm lost its initial advantage in such production. Swan reorganized and modernized the factory in 1892 and installed American-designed machinery. Later the firm gave some attention to the production of film. In 1894 Swan was elected a Fellow of the Royal Society and later was knighted, but this recognition came principally for his work with electricity rather than photography.[30] Had his energies remained directed toward photography during the 1880's, a man of his chemical training and practical experience might well have performed in England what Eastman did in the United States.

Another early English producer of gelatin plates was B. J. Edwards and Company of Hackney. Edwards began as a professional photographer in 1878 and very soon initiated production of dry plates. He, like Swan, developed a plate-coating machine at an early date. In 1886 the firm initiated English production of orthochromatic plates. During the 1890's the company employed J. W. Findlay, a chemist, to aid in the production of gelatin emulsions.[31]

In 1879 Alfred H. Harman founded a dry plate company which by the end of the century was one of England's largest and best-established photographic materials manu-

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30. Swan, pp. 120 and 122, and Photographic News, XLII (September 9, 1898), ii.

31. Photographic News, XLI (1897), 847, and Photographic Journal, LXXXIV (1944), 194.

facturers. Initially Harman named the firm Britannia Works Company, Ltd., but late in the 1890's the firm assumed the name of the popular trademark of its products, Ilford. In 1891 Harman hired J. J. Acworth as a chemist, but the owner's concern over secrecy disturbed the young chemist, and, therefore, he left to study chemistry in Germany. Upon his return, Acworth founded the Imperial Dry Plate Company. Until 1898 Ilford made a good profit without relying on scientific research, but in 1898 Harman hired Frank Forster Renwick (1877-1943), a young chemist trained in the technical schools of London and South Kensington, to conduct investigations on plate emulsions. Harman again forced his chemist to work alone behind locked doors with only primitive equipment. In 1899 a new manager succeeded Harman, and conditions improved. A second chemist, B. V. Storr, joined Renwick in the laboratory, where they concerned themselves with the work of Hurter and Driffield. Ilford continued to employ chemists for research purposes into the twentieth century.[32]

These early English dry plate firms placed England in the lead in the production of gelatin plates. Though English photographers were reluctant to adopt gelatin plates in the middle 1870's, photographers elsewhere were

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32. Photographic Journal, A, LXXXV (1945), 222-223; Photographic News, VL (1901), 1; Photo-Miniature, IV (1902-1903), 445-446; and British Journal of Photography, LIV (1907), 922 and 925.

even more reluctant, with the result that English producers entered upon production early and gained a position of dominance. England also had two other advantages which aided its development of the plate industry. First, England was the principal producer of quality glass for the glass plates. Glass of uniform surface was very important for plate producers. Therefore, England could supply better quality plates at less cost to Germany, for example, than many of the German firms could manufacture them. Second, dry plate manufacturing required considerable capital because of investments required for plant and machinery. In the plant the air needed to be kept free of smoke and dust, the temperature and humidity needed to be carefully controlled, and the water needed to be filtered and purified. In the last quarter of the nineteenth century, England had available the largest amount of investment capital.

The early plate producers tended to be practical men with little or no formal scientific training. They were attentive to the new ideas presented in the British photographic journals and conducted investigations of their own. A producer like Swan was initially at an advantage because of his previous chemical and photographic experience. Within a few years, however, these leading firms which had initially supplied England and a large part of the rest of the world with dry plates were

challenged by other companies in England, France, and the United States.

A number of dry plate manufacturers began production many years after the first commercial production of plates in England. Among the smaller companies there was R. W. Thomas and Company, Ltd., where in 1891 J. Sandell, chemist and director of the plate factory, produced the first halation-free plates. In 1897 Sandell established his own factory in London. Other firms included Marion and Company, Ltd., of London; Cadett and Neall of Ashtead; Barnet Dry Plate Factory (originally Elliot and Son); Warwick Dry Plate Company; and Imperial Dry Plate Company, Ltd., of London.[33]

In summary, England took the first steps in introducing and manufacturing gelatin dry plates. Amateurs were responsible for discovering the unique advantages of gelatin emulsions, and the British photographic journals provided a means of communication and exchange of ideas. Yet accompanying the renewal of factory production was an increase in secrecy with regard to processes, as

33. Thomas and Sandell: British Journal of Photography, LIV (1907), 11; Photographic News, XLII (September 9, 1898), xii; and Wentzel, p. 12. Marion & Co. Ltd: British Journal of Photography, LIV (1907), 646, and July 26, Supp. 4. Cadett & Neal: British Journal of Photography, XLVII (1900), 12, and Photographic News, XLII (September 9, 1898), vi. Barnet: Photographic News, XLII (1898), 154. Warwick: Photographic News, XLII (September 9, 1898), x. Imperial: Photographic News, XL (1896), 317; Photographische Korrespondenz, XXXVII (1900), 744; and British Journal of Photography, LIV (1907), 679.

illustrated by Swan's trade secret, ripening. Some of the earliest successful manufacturers, namely the Liverpool Dry Plate Company and Mawson and Swan, possessed the advantage of having already produced collodion dry plates. Therefore, supply and marketing channels had been established prior to production of gelatin plates. English producers possessed the advantage of being the first producers, holding an edge on foreign competition in having an excellent supply of glass plates and having access to capital for the necessary machinery and plants. As a result of these advantages, England retained her position as the leading dry plate producer of the world into the twentieth century.

The early producers were practical men with little academic training; however, by the end of the century the large and competitive firms had begun to pay more attention to science and scientifically trained personnel. Companies such as Edwards, Thomas, and Britannia (Ilford) hired academically trained chemists in the 1890's. At the turn of the century, chemical research was beginning at Ilford and Wratten and Wainwright. In both of these laboratories, the influence of the scientific work of a decade before by Hurter and Driffield was being felt. As the size of the firms increased, they could afford the "luxury" of a chemist or two to experiment with new ideas, but as was to become increasingly more evident in the first decade of the new century, when the size of firms and the

competition increased, scientific investigations, as in the dye industry beginning thirty years earlier, became a necessity for survival. Though English producers did turn to science at the end of the century, they were somewhat behind firms in the United States, France, and Germany in research. Finally, the introduction of film photography about 1890 brought strong competition to these English producers. In response, some tried to produce film, in particular, those firms which were becoming science oriented.

France

Gelatin dry plate production began in France a few years after English firms began manufacture; however, even after the French began production, English establishments continued to find markets in France. The firm of Lumière in Lyon soon became the leading French producer of dry plates, and the eventual success of the company in this branch of manufacture encouraged extension to other commodities such as paper, movie film, and cameras, and photographic chemicals. The firm's interest in chemicals encouraged the establishment of a small research laboratory where fundamental studies in organic developer structure were conducted.

Antoine Lumière and his two sons, Auguste and Louis Jean, founded in 1883 the Société des Plaques at Lyon. With about ten employees, the firm produced at first about

fifty-five to sixty dozen gelatin silver bromide plates per day. During the first year, output totaled 18,000 dozen plates. By the end of the century, output had risen to about 6,000 dozen plates per day. The Lumières had achieved this increase by installing a substantial amount of machinery, including ninety electric motors and two ice machines used to help cool the emulsion room. In the early 1890's the company also began production of photographic paper and chemicals. At this time the two sons, Auguste and Louis Jean, with the able assistance of Alphonse Seyewetz initiated studies of organic developers in the small company laboratory at Lyon. The studies conducted at this laboratory and those conducted by Andresen at the Agfa laboratory laid the foundation for understanding the relationship between the structure of certain organic compounds and developing potential. The Lumière brothers and Seyewetz also studied the effects of photographic intensifiers and fixing baths. At the turn of the century, they initiated investigations of methods of producing colored photographs and about 1907 began production of colored prints. Though this work was not of immediate commercial importance, by the turn of the century word had reached other photographic materials producers such as Eastman that the Lumière company was conducting research in color photography. This led Eastman to emphasize chemical research to a great

Figure 2. The Research Laboratory of the Lumières at Lyon.

degree and eventually led to the founding of the Kodak Research Laboratories under the direction of C. E. Kenneth Mees. Therefore, various companies within the photographic industry kept informed of the activities of their competitors, and activities in one plant stimulated activity in others.[34]

Though in terms of value of output dry plates accounted for 58% of Lumière's business in 1899-1900, the company continued to search for improved products and new ideas. When the Lumière brothers encountered success in the laboratory, they turned to commercial exploitation of the new ideas. As a result, the company expanded into production of paper, chemicals, movie cameras, and film.[35]

Other French companies were producing dry plates in the 1890's. These included Hanriau and Guilleminot, both of Paris. The latter produced anti-halation plates similar to those produced by Sandell in London. The second largest French photographic materials manufacturer was Société An. des Plaques Pellicules et Papiers Photographiques J. Jougla in Paris. Early in the twentieth century Jougla and Lumière merged their operations.[36]

34. Agenda Lumière (Lyon, 1911), pp. 3-5; Wentzel, p. 15; and Eder, "Ein Besuch in der Trockenplattenfabrik von A. Lumière et fils in Lyon," Photographische Korrespondenz, XXXVIII (1901), 73-83. Dry plate production: 1883, 18,000dz; 1886, 110,000 dz; 1890, 350,000 dz; 1896, 2,500,000 dz.

35. Eder, "Ein Besuch...," pp. 82-83.

36. Photographische Korrespondenz, XXXVII (1900), 743; Wentzel, pp. 12 and 15, and Kühn, p. 142.

In summary, the French dry plate companies entered upon production a little later than the English firms and therefore faced an uphill battle in capturing the French market. In spite of the advent of film photography, Lumière continued to increase dry plate output throughout the century. The Lumière dry plate business provided sufficient revenue for the establishment and maintenance of a small research laboratory with at least three chemists conducting original investigations. The continued research studies conducted by this firm permitted it to enter upon film and cinema camera production and later color photography. These studies, in turn, helped to stimulate further establishment of scientific facilities by the Eastman Kodak Company at Rochester.

Germany

In view of Germany's strong position in the optical and camera fields, it is surprising to find that it did not produce a strong dry plate industry during the nineteenth century. About 1879 dry plate production began in Germany, and in a few years a number of small firms were in operation; but the companies remained small, unable to compete effectively with the British producers of good quality, inexpensive plates. Though German companies had excellent emulsion formulas and continued to introduce significant advances in emulsions, the problem for them was the supply of good quality glass. Plate glass was

produced in England and Belgium, though the glass from Belgium was not well cut and, therefore, not as satisfactory as that from England. Although Germany placed a tariff on dry plates, she also levied a tariff on plate glass, thus defeating the protective aspect of the dry plate tariff. Therefore, the English continued to compete effectively with German producers. In addition, England's earlier beginning in production and export encouraged large scale production and the economies of production derived therefrom, while German producers entered later and remained small because of the British competition. As in the optical and photographic paper fields, some scientifically trained personnel entered upon dry-plate production, but the economic limitations prevented the emergence of large-scale operations during the nineteenth century.

The earliest production of dry plates in Germany came in 1879. The firm of Johann Sachs, Glasserei für photographische Trockenplatten, initiated production in March of 1879. At first Sachs coated the plates by hand, but soon he introduced coating machinery. Shortly, F. Wilde at Görlitz also began production of plates.[37]

One of the earliest and eventually most important dry plate producers was Dr. Carl Schleussner (1830-1899). Schleussner had attended the Darmstädter Gymnasium and

37. Photog. Korresp., XXXVII (1900), 743; Wentzel, p. 14; Stenger, p. 29.

Polytechnikum, where he had studied pharmacy. In 1856 he had begun study of chemistry at the University of Giessen and obtained a Ph.D. degree there in 1857. He then had worked in a pharmacy in Frankfurt a. M. and had conducted investigations of the chemistry of photography. Later he had established his own chemical laboratory for medical and legal investigations as well as for production of photographic materials such as collodion and silver nitrate. In the late 1870's his interests turned increasingly to photographic chemistry, and in 1879 he began laboratory production of gelatin dry plates. Within a year he initiated commercial manufacture. Although he coated his dry plates by hand at first, in 1885 he introduced coating machinery. The business grew substantially during the 1880's, and in the early 1890's Schleussner outgrew his four-story factory building. In 1892 operations were moved to a new factory building where the most modern production machinery and techniques were employed. During the 1890's Schleussner turned over control of the firm to his two sons and a son-in-law, and in 1897 the company became an Actiengesellschaft. The firm retained a reputation for production of high-quality plates and kept alert to improvements in emulsions. In less than a year following Roentgen's discovery of X-rays, the firm was producing plates specially sensitized for

X-rays.[38]

In 1881 Westendorp established a dry plate company in Köln and later was joined by Wehner in the operation of the factory. In 1889 J. B. Gebhardt also established a plate works in Köln, and during the early 1890's the operations of Westendorp, Wehner, and Gebhardt were merged. The new company was known as Westendorp und Wehner A.-G. In 1898 this new company and that of Schleussner entered upon a pooling agreement (Interessengemeinschaft) in which the market and the profits were distributed between the two firms.[39]

Therefore, at the end of the century a merger and pooling movement appeared in the German dry plate industry. Such activity was common among many German industrial concerns during the last two decades, particularly among the firms in the dye industry and in other fine chemical production. Hence this organizational structure was not a feature unique to the dry plate industry.[40]

~~Another dry plate producer of importance was~~ Otto Perutz of Munich. Perutz had established in 1871 a chemical and pharmaceutical factory at Munich, but with the introduction of the dry plate into Germany, his

38. *Photog. Korresp.*, XXXVII (1900), 58-59; *Brit. J. Photog.*, XLVII (1900), 125; *Pop. Photog.*, XXXVIII (1956), 120 and 130; Wentzel, pp. 14-15; Kühn, pp. 92-93.

39. *Ibid.*, p. 116; Wentzel, p. 15.

40. John Beer, *The Emergence of the German Dye Industry* (Urbana, 1959), pp. 115-133.

attention turned to gelatin emulsions and dry plates. At first he went into partnership with J. B. Obernetter, who had been producing photographic paper, and they utilized Obernetter's gelatin emulsions for coating dry plates. In 1882 Perutz entered into association with Dr. Herman W. Vogel in order to utilize Vogel's discovery of the color sensitization of aniline dyes on plates and his subsequent studies with dye sensitizers in the commercial production of dry plates. Perutz continued his interest in producing orthochromatic plates. When Adolf Miethe (b. 1862), Professor of Photochemistry and Spectroanalysis at the Technische Hochschule at Berlin-Charlottenberg, and Dr. Arthur Traube (b. 1878), a student of and later private assistant to Miethe, discovered the excellent sensitizing properties of "ethyl-red" in 1902, Perutz put Traube in charge of the technical department of his factory and soon began production of the first panchromatic plates. Using spectroscopic methods, Miethe and Traube had been deliberately seeking such a sensitizing dye. As soon as they had discovered "ethyl-red," they had patented its use in photography.[41] Therefore, the Perutz firm provides another example of trained chemists with a practical orientation, such as Vogel, Miethe, and Traube, working in close association with a commercial producer. The work

41. *Ibid*., p. 16; Eder, pp. 473-475; *Photog. Korresp*., XL (1903), p. 578.

of Miethe and Traube demonstrates that they saw a specific deficiency in the color sensitivity of dry plates, sought to solve the problem, and patented the results of their work. The Perutz factor had a laboratory from an early date, but research facilities expanded when Traube joined the company.

The company which in the twentieth century became the dominant photographic manufacturer of Germany, Actiengesellschaft für Anilin-Fabrikation (Agfa), began production of dry plates in 1893. Agfa had been founded at Berlin in 1871 by Carl A. Martius and Dr. Paul Mendelsohn-Bartholdy as an aniline dye company. The studies in the late 1880's of Momme Andresen in aniline derivative photographic developers had stimulated the establishment of a separate photographic division of the firm in 1889. Andresen himself supervised the initial production of dry plates in 1893. From the first, Agfa produced anti-halation plates, placing a dyed, insensitive gelatin coating between the glass and the emulsion. The dry plate business of Agfa prospered, but even at the end of the century its production had not yet challenged British producers. However, this company was laying the foundation for a strong commercial position in the twentieth century with its close association between the laboratory of Andresen and its production facilities.[42]

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42. Beer, pp. 43 and 51; Wentzel, pp. 12-13 and 17; Eder, p. 432.

In 1890 another chemical dye company, Chemische Fabrik Hauff in Feuerbach, began production of dry plates. As with Agfa, Hauff had been established in 1870 for the production of benzene derivatives. Late in the 1880's the company had begun production of photographic preparations. At that time the son of the founder of the firm, Dr. Fritz Hauff, and another academically trained chemist, Dr. A. Bogisch, had initiated investigations of developing preparations and had successfully prepared and marketed a number of new developers. Although dry plate production was initiated in 1890, throughout the decade the company emphasized its developers, and it was only in the early twentieth century that it began large-scale production of plates.[43]

A number of other dry plate companies were established in the larger metropolitan areas of Germany during the period 1880-1900; however, most of these remained small, serving only a local area or producing plates for a specialized market.[44]

In Vienna a number of small firms began production of dry plates in the 1880's. One of the earliest producers was Carl Haack (1842-1908), a chemist interested in photography, who started a dry plate

43. Ibid., pp. 779-780; Kühn, p. 84.

44. Photog. Konesp., XXXVII (1900), pp. 119-120 and 129; Wentzel, pp. 14-15.

factory in Vienna in 1879 but sold the company to Engelhardt and Schattera in 1888. Langer G.m.b.H. began production in 1888 and early in the twentieth century merged operations with Schattera.[45] Several other small producers initiated operations in the early 1880's, but most of them either went out of business or sold their plants to larger producers. At the end of the century the three major producers in Vienna were Langer, Schattera, and Hrdlička. Some of these companies, such as Hrdlička, which initiated dry plate production in 1899, had a close association with the activities of the Graphische Lehr-und-Versuchsanstalt, directed by J. M. Eder. Hrdlička himself was a chemist and had taught at the Versuchsanstalt.[46]

Even though a number of dry plate companies appeared in Germany, the British and French producers continued to find strong markets in Germany. One of the serious problems for German producers was obtaining good quality, inexpensive plate glass. England had a number of producers of glass plates for photography dating from the 1850's. Later, in France and Belgium glass plate producers appeared, but in this vital field Germany had no producers of importance. At the turn of the century Carl Menzel

45. G.m.b.H. stands for Gesellschaft für beschränkten Haftung; this is a limited liability corporation. An Actiengesellschaft is a joint stock company without limited liability.

46. Photog. Korresp., XVI (1879), 193; XXXVII (1900), 171; XLVI (1909), 585; Eder, pp. 431 and 779 (notes); Kühn, p. 141.

founded a glass factory at Lommatzsch, and soon other plate glass companies arose; consequently, Germany could then begin to compete with plates from Britain and France, although British imports continued to rise through 1906.[47]

Many of the German dry plate companies had close connections with chemistry. Some of the founders of firms, such as Schleussner, Perutz, Haack, and Hrdlička, were trained chemists. Some companies grew out of chemical plants which were already established, such as Perutz, Agfa, and Hauff. Therefore, the earlier experience with chemistry aided in developing successful emulsion formulas. Agfa and Hauff, of course, came into the photographic field by way of production and investigations of aniline derivative photographic developers. By the end of the century a striking number of these dry plate firms had research facilities of some kind. Companies that did included Schleussner, Perutz, Agfa, Hauff, and Hrdlička. From these facilities came such significant advances in photographic technology as a large number of new organic developers and plates of extended range color sensitivity. The fundamental studies of Andresen advanced understanding of structure and properties of an important

47. Ibid., pp. 47-52; Wentzel, p. 20; Photog N., XLVIII (1904), 711-712; Brit. J. Photog., LIV (1907), 114-115. British exports of dry plates to Germany, by weight, in kilos: 1903: 9,600; 1904: 23,300; 1905: 38,700; 1906: 83,000; Ibid., 114. Note: exports of plates and glass dipped from 1901 to 1903, probably reflecting the rise of German glass production, but total weight and value from 1901 to 1904 increased nearly five-fold. See Ibid., 144.

class of organic compounds. Yet, as important as the scientific connections are for successful commercial production in a technical field like photography, the presence or absence of other basic economic factors also plays an important role in the development of an industry. The initial head start of British plate makers and the lack of a good, inexpensive supply of plate glass put German producers at a disadvantage which, in spite of their scientific orientation, they could not overcome by the end of the century.

Belgium, Switzerland and The Netherlands

In spite of England's early lead in the production of dry plates, a few small firms appeared in Belgium, Switzerland, and The Netherlands. One of the early producers of gelatin bromide emulsion was Désiré Charles van Monckhoven (1834-1882), a leading Belgian photographer and photochemist. About 1880 he commercially produced the emulsion in his laboratory at Ghent and sold the material to two Belgian plate factories, one in Ghent and one in Courtrai. In Switzerland J. H. Smith, an outstanding photochemist, established a plate factory at Zurich-Wollishofen in 1889. As early as 1878 the firms of Wegner and Mottu had begun dry plate production in The Netherlands.[48] These firms in Belgium, Switzerland, and The Netherlands

48. Eder, pp. 428 and 431; Wentzel, pp. 15 and 17; Photog. Korresp., XXXVII (1900), 743; Poggendorff, III, II (1858-1883), 930-931.

were small and were of little economic significance; yet they demonstrate the relative ease with which a company could be established, especially during the early 1880's before very large producers such as Ilford had emerged and before film photography had begun to compete.

United States

Photographers in the United States were reluctant to adopt the new gelatin dry plates; nevertheless, in 1879 and 1880 a few dry plate producers appeared. Soon thereafter photographers came to appreciate the advantages of dry plates, and some of the early manufacturers became major producers. Like the English producers, the American pioneers were not academically trained chemists but were generally professional photographers. One of the early producers, George Eastman, built a substantial business which later provided the financial foundation for his experimentation with and production of photographic film. ~~When film photography became a commercial success, the~~ Eastman company then shifted emphasis from dry plates to film and cameras. Meanwhile, three firms in St. Louis developed excellent emulsions and by the end of the century were producing a large part of the American output. The dry plate industry in the United States, therefore, did not exhibit a close association with scientific personnel; however, dry plate production was the initial propellant that thrust the Eastman company into the position of world

leader in the photographic industry.

Word of gelatin dry plates reached the United States in the middle and late 1870's by way of the British photographic journals, but initially there apparently was little response from either photographers or potential commercial producers. The substantial increase in sensitivity over wet collodion plates required that photographers handle gelatin plates with great care. In addition, problems of light leaks in cameras and plate holders as well as difficulties with light in dark rooms did not make the new plates particularly attractive at first. Also, they were more expensive than wet collodion plates. Yet once the photographers became acquainted with their use, and much of the initial indifference to them was overcome, the demand for plates increased.

Two of the earliest manufacturers of dry plates were in operation by 1879. Albert Levy of New York began production in the late 1870's and immediately made an appeal to amateur photographers by producing both dry plates and inexpensive dry plate cameras. Little is heard of Levy's operations after 1880.[49] John Carbutt (1832-1905) of Philadelphia began production of dry plates in 1879. Carbutt was born in England and had come to the United States in 1853. He had established a photographic

49. Taft believes Levy may have produced dry plates in 1878 or even earlier. See Robert Taft, Photography and the American Scene (New York, 1964), p. 503 (note #381).

gallery and later had become official photographer for the Canadian Pacific Railroad. In the 1860's he had operated a studio in Chicago and in 1871 had moved to Philadelphia, where he had worked on photo-mechanical processes. He investigated the new gelatin emulsions and in 1879 began commercial production of gelatin plates, marketing them under the name Keystone Plates. Carbutt's business expanded during the 1880's, and he added lantern plates and film to his production. He is also reputed to have been the first American producer of orthochromatic plates. He continued in business in Philadelphia (Wayne Junction) until the end of the century when he moved operations to Boston, where he went out of business shortly before his death.[50]

E. and H. T. Anthony and Company of New York, the old supply house and manufacturer from the early days of the daguerreotype, began production of dry plates about 1880, marketing them under the name Defiance Plates. Soon, however, Anthony turned to the Eastman Dry Plate Company as a source for plates and abandoned its own production. The other old American supply company, Scovill Manufacturing Company, did not manufacture gelatin plates but did market complete camera outfits which were designed to appeal to amateur photographers. Another early

50. Joseph Jackson, Encyclopedia of Philadelphia (Harrisburg, 1931), II, 367-368; Dictionary of American Biography (New York, 1929), III, 485; Photo-Miniature, IV (1902-1903) ad.

manufacturer was Cross of Indianola, Iowa, who initiated production in 1880 but did not continue operations for long.

From a very early date St. Louis was a center for the production of dry plates. Gustav Cramer (b. 1838) and H. Norden commenced manufacture of plates on a small scale in 1879, and the business grew gradually. Cramer was a German immigrant who had received schooling in chemistry in Germany before coming to the United States in 1859. After arriving in St. Louis, Cramer had learned the art of photography and opened his own studio. After the initial success of Cramer and Norden in producing dry plates, Norden left the business in 1883; and Cramer assumed full control of the company, which became the G. Cramer Dry Plate Company. During the late 1880's and the 1890's, the business grew substantially, and, therefore, modern machinery and equipment were employed. Because domestic glass lacked clearness of color and smoothness of surface, the glass base for plates was imported from England and Belgium. By the end of the century, when the company was one of the largest producers in the country, Cramer had a branch office in New York and exported plates to North and South America, Europe, and Australia.[51]

In 1883 A. R. Huiskamp and M. A. Seed established

51. Ernest D. Kargau, Mercantile, Industrial, and Professional Saint Louis (St. Louis, 1902), pp. 410-412; William Hyde and Howard L. Conrad, Encyclopedia of the History of St. Louis... (St. Louis, 1899), Vol. I, pp. 511-512.

near St. Louis a dry plate factory, the M. A. Seed Dry Plate Company. They operated offices and a warehouse in the city and placed their production facilities nearby at Woodland, Missouri. As demand for plates increased, modern production machinery was introduced. In addition to manufacture of high-quality gelatin dry plates, which were the principal product of the firm, the company also made lantern slides, transparencies, developers, and some celluloid film. At the end of the century the firm employed more than one hundred men, some of whom included experienced chemists. Shortly after the turn of the century, the Eastman Kodak Company purchased controlling interest in the firm but left the production facilities at St. Louis.[52]

Ludwig Frederick Hammer (b. 1834) founded a third important plant for the production of dry plates in St. Louis in 1891. Hammer was born in Germany and had come to the United States in 1854. When he had first arrived in St. Louis, he had worked for a tannery and in a few years established his own plant. During the 1860's he had learned the art of photography and in 1869 had opened his own studio. In twenty years his operations had expanded into a large photographic supply business. In 1891 Hammer and William J. Althans organized the Hammer-Althans Manufacturing Company and began plate

52. Kargau, p. 413.

production. When Althans withdrew from the firm in 1892, the company became the Hammer Dry Plate Company, and the business expanded rapidly.[53]

At the end of the century, St. Louis was the dry plate manufacturing center of the United States, reputed to be producing more than a million dollars' worth of plates annually and supplying three-quarters of all plates used in the Western Hemisphere. The largest part of this output was from the two largest producers, Cramer and Seed.[54]

Although St. Louis became the dry plate center of America, the initial activities of a dry plate manufacturer, the Eastman Dry Plate Company in Rochester, New York, made that city the photographic center of the world. George Eastman (1854-1932) was born in upstate New York the son of an operator of a commercial college and received about eight years of public schooling before he went to work in an insurance office. In 1874 he became a junior bookkeeper in a Rochester bank, a position he held until after his own business enterprise was well under way. In the fall of 1877 Eastman purchased some photographic equipment and took lessons in wet collodion photography

53. Ibid., pp. 414-415; Hyde and Conrad, II, 977-978.

54. Ibid., III, 1729; Census Bureau statistics for 1898-1899 indicate that the value of output of the three firms was $584,496, Census of Manufactures, 1900, I, pp. 346-349; the one million dollar figure comes from Hyde and Conrad for a period about a year and a half later.

from a local photographer. Soon photography became an all-consuming interest for him, and in 1878 he began to experiment with the wet collodion process. At this time Eastman read an article in the British Journal of Photography Almanac in which the formula and directions were given for preparation of gelatin dry plates, and Eastman began at once to work with gelatin emulsions, using at first the Bennett formula.[55] Soon he began to examine carefully the American and British photographic journals and also to study the French and German languages so that he could read their journals. In June of 1879, with commercial production of gelatin plates already in mind, he built and successfully operated a glass coating machine. In September of 1879 he applied for a patent: "Improved Process of Preparing Gelatin Dry-Plates."[56] He obtained the United States patent and registered it in England, France, Germany, and Belgium, demonstrating his interest in securing his rights to his improvement in the processing of plates.[57] Hence the photographic journals freely

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55. Goodwin vs Eastman, I, 318; quotations from letters and notes of Eastman in Carl W. Ackerman, George Eastman (London, 1930), pp. 25-26. Remember that Charles Bennett had also published the description of the ripening process.

56. Ackerman, p. 28.

57. Ibid., pp. 26-30; Eastman sold English rights to his process to Mawson and Swan in late 1879. A letter written to Mawson and Swan at that time indicates that Eastman had in mind to start production of plates "on a large scale..." and he expected "if necessary, to put the price down to a point which will prevent miscellaneous competition." Ibid., p. 30.

provided the information on the production of gelatin dry plates which stimulated Eastman's interest in the subject; but when he developed new ideas, he immediately acquired patents in order to preserve his opportunity to exploit them. Swan in England did much the same thing, only he kept his ideas as trade secrets instead of patenting them.

In August of 1880 Eastman made preparations for initiating production. Negotiations with the Anthony company led to the filling of Anthony's first order in December of 1880. On January first, 1881, Henry A. Strong, a wealthy Rochester whip manufacturer, became a partner in the new firm, the Eastman Dry Plate Company. The response to Eastman's first plates was quite favorable, and orders came from leading photographers all over the country. Soon operations were on a large scale, and sales were made only to wholesale establishments. In spite of some early difficulties in the making of the emulsion, the company prospered under the technical supervision of the amateur chemist Eastman. At first a large part of the output went to the Anthony company, and it, in turn, supplied most of the chemical supplies. However, as Eastman became interested in paper film photography and hence turned to production of photographic paper as well as dry plates, the relations between the two companies deteriorated, and relations between them remained very poor into the twentieth century.[58]

58. Goodwin vs Eastman, I, 318 and 362; Ackerman, pp. 30-32, 37-38, 42-43, 53-54, 71, 93-94; Taft, p. 391.

From 1884 Eastman's interest focused on film photography. Thereafter, dry plate production continued to be an important part of the business, but production of both film and roll film cameras grew rapidly and during the 1890's became the financial base for the rapid expansion of the company. Early in the new century the Eastman company acquired control of the Seed Dry Plate Company, one of St. Louis's largest producers, and two smaller companies, the Stanley Dry Plate Company of Newton, Massachusetts, and the Standard Dry Plate Company of Lewiston, Maine.[59] Eastman purchased these companies in order to obtain trade secrets in production of gelatin emulsions so that they might be used by the Eastman company not only for dry plates but for film as well. Therefore, though dry plate production had become a relatively small part of the Eastman operations by 1900, it had brought George Eastman into the photographic business and had provided the financial foundation for his experiments and commercial exploitation of film photography.

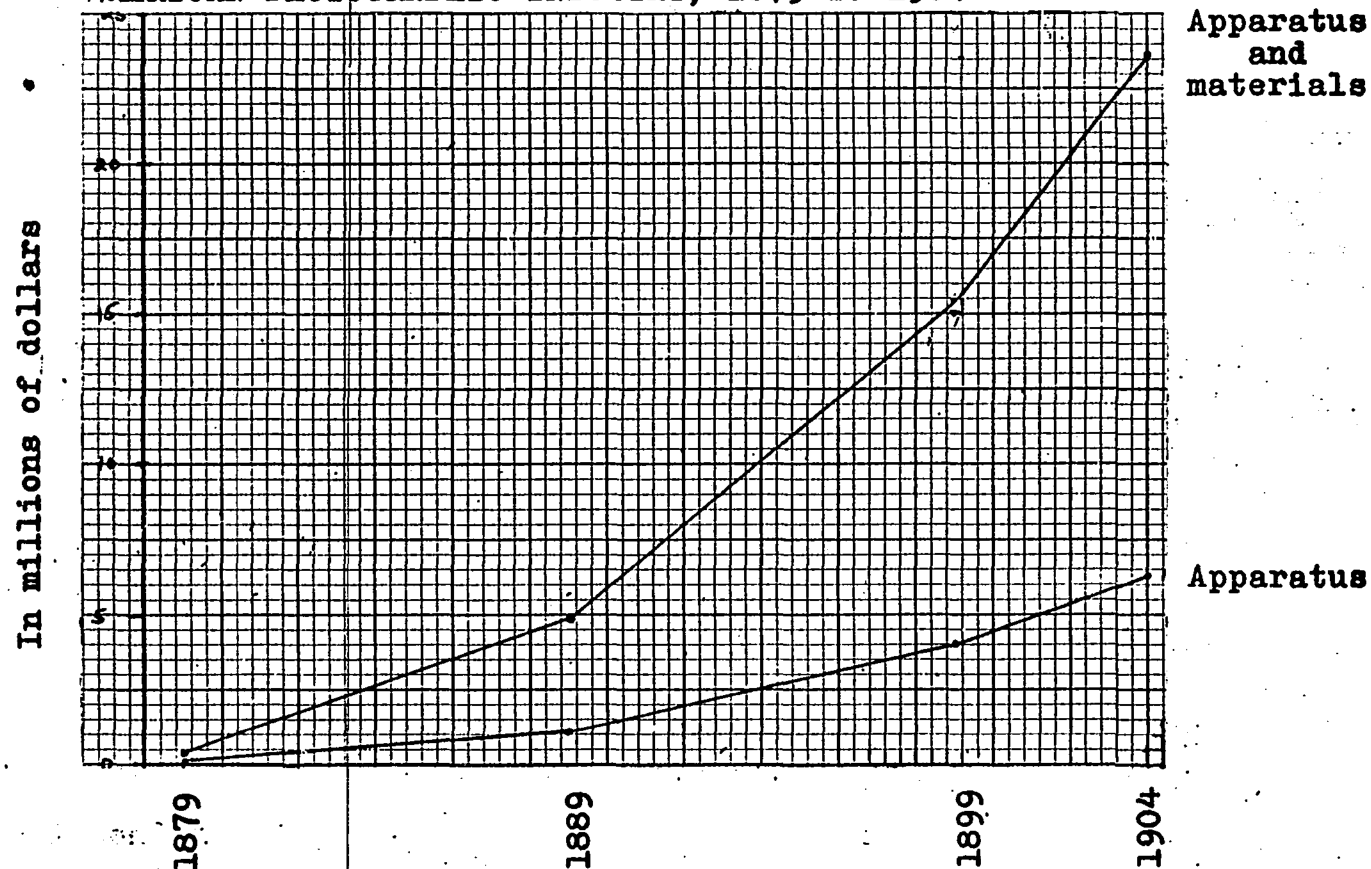
At the end of the century the American dry plate industry was concentrated at Rochester and St. Louis. It is difficult to determine why these two locations should have emerged as the centers for activity when in 1890 there were dry plate companies in nearly every major

59. Ackerman, p. 181.

TABLE 1

VALUE OF OUTPUT OF THE

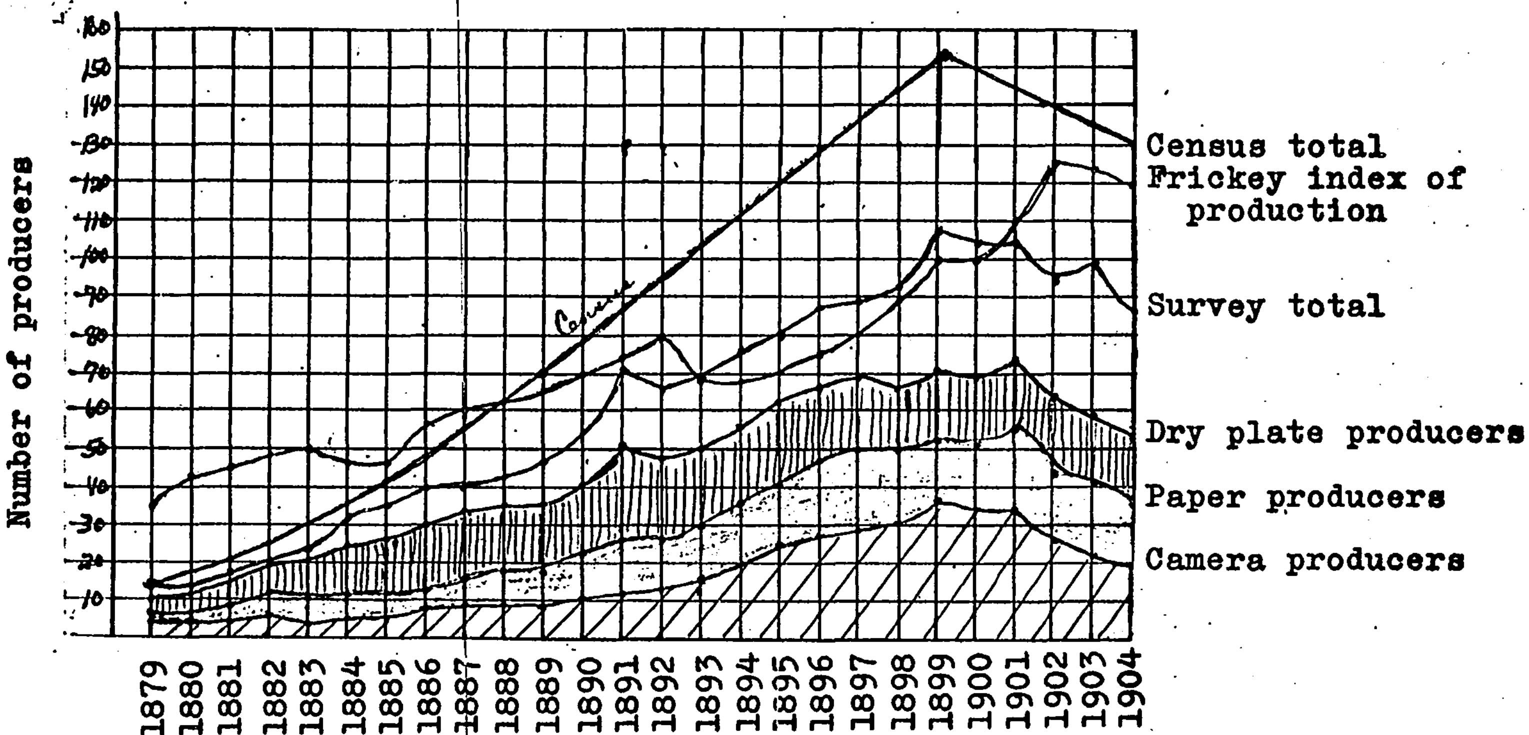
AMERICAN PHOTOGRAPHIC INDUSTRY, 1879 TO 1904[a]



[a]See Appendix

TABLE 2

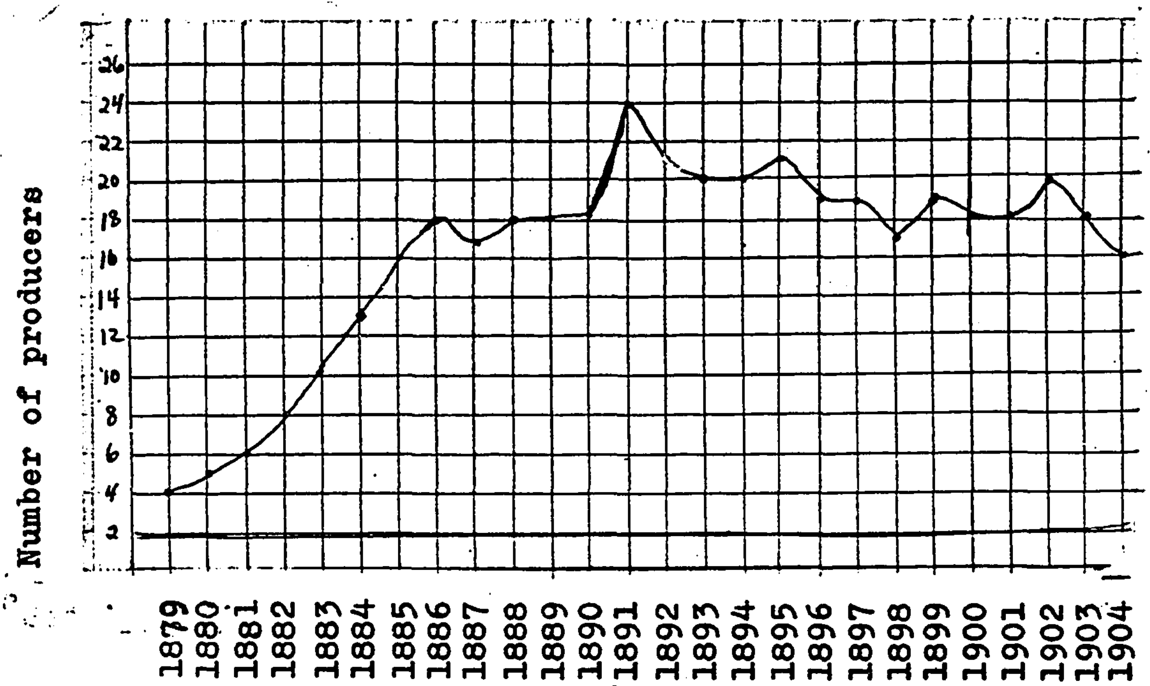
NUMBER OF AMERICAN PHOTOGRAPHIC MATERIALS AND APPARATUS MANUFACTURERS, 1879 TO 1904[a]



[a]See Appendix

TABLE 3

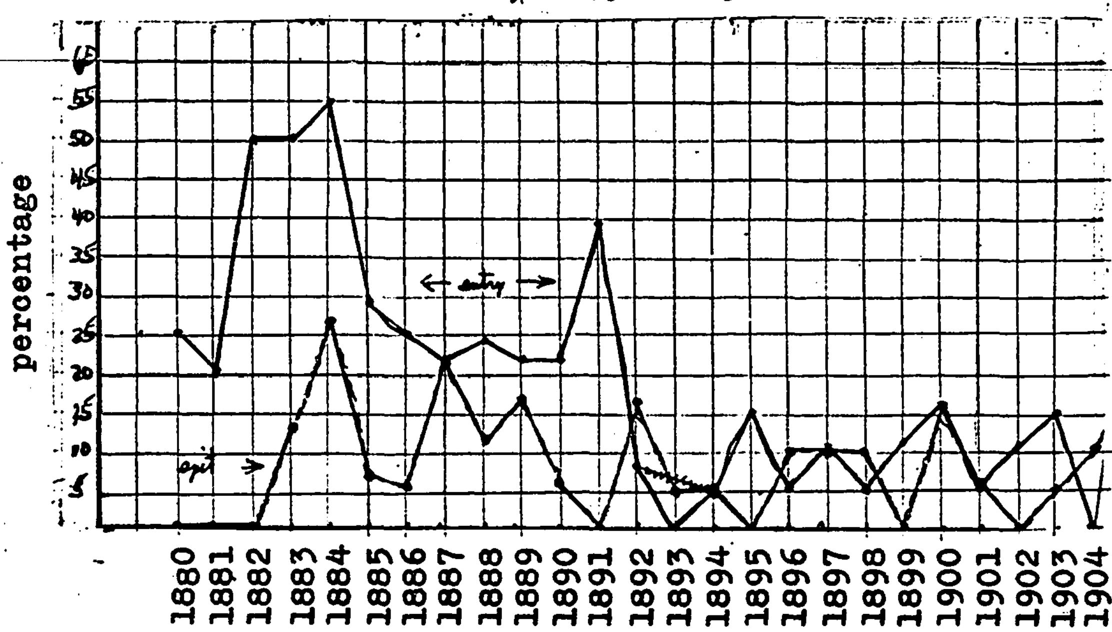
NUMBER OF AMERICAN DRY PLATE MANUFACTURERS, 1879 TO 1904[a]



[a]See Appendix

TABLE 4

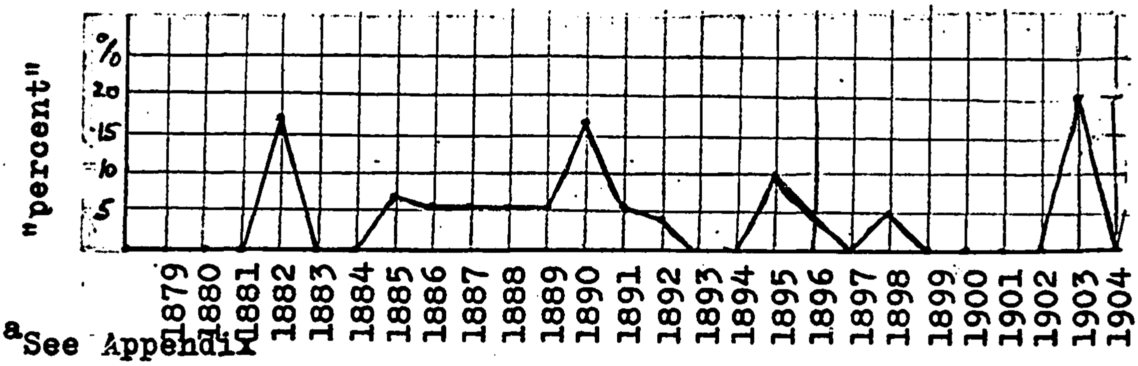
ANNUAL ENTRY AND EXIT RATES FOR AMERICAN DRY PLATE MANUFACTURERS, 1879 TO 1904[a]



[a]See Appendix

TABLE 5

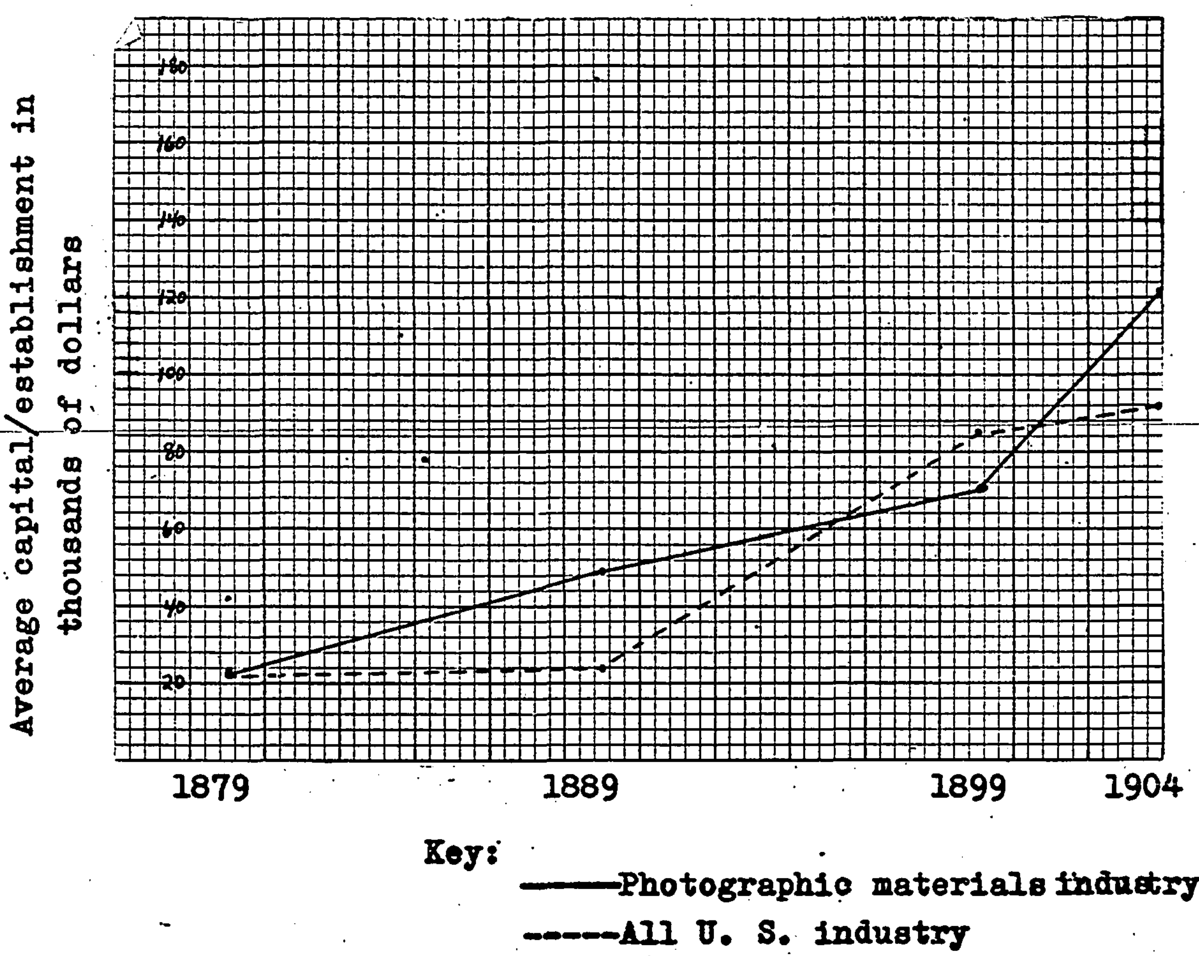
ANNUAL MERGER RATE FOR UNITED STATES DRY PLATE MANUFACTURERS, 1879 TO 1904[a]



[a]See Appendix

TABLE 6

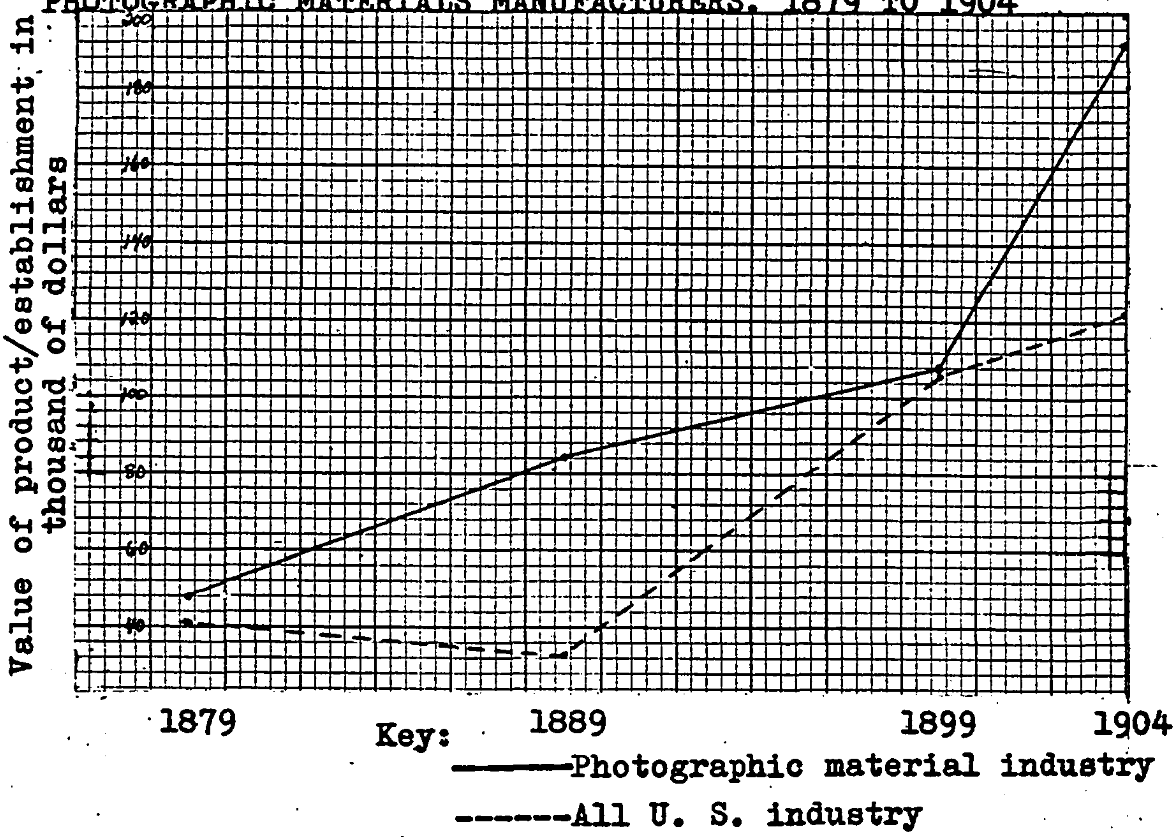
AVERAGE CAPITAL PER ESTABLISHMENT FOR AMERICAN PHOTOGRAPHIC MATERIALS MANUFACTURERS, 1879 TO 1904[a]



[a]See Appendix

TABLE 7

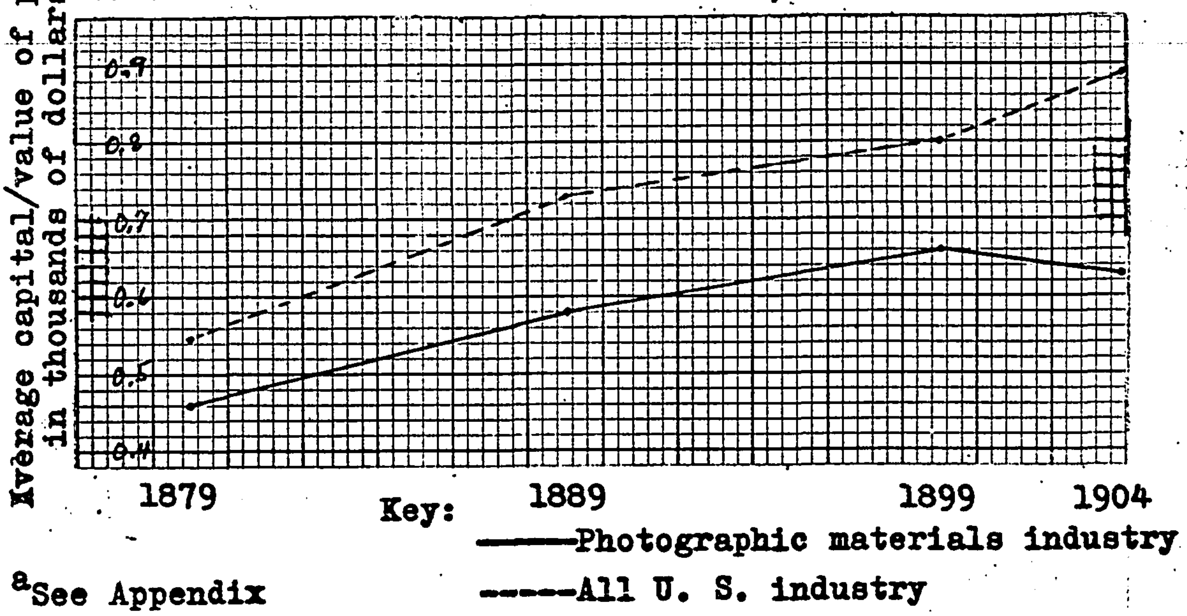
VALUE OF PRODUCT PER ESTABLISHMENT FOR AMERICAN PHOTOGRAPHIC MATERIALS MANUFACTURERS, 1879 TO 1904[a]



[a]See Appendix

TABLE 8

AVERAGE CAPITAL PER VALUE OF PRODUCT FOR AMERICAN PHOTOGRAPHIC MATERIALS MANUFACTURERS, 1879 TO 1904[a]



[a]See Appendix

metropolitan area in the country. The quality of the emulsion was probably the most important factor. Many companies entered upon production for a short time and then, when their emulsions were not competitive, ceased operations. However, when Eastman encountered difficulties with his emulsions he went immediately to England to consult experts there. He continued to improve both his dry plates and film emulsions by acquiring companies which had superior recipes. In the case of St. Louis, two of the three major producers located there were German emigrants who had acquired some scientific schooling in Germany and had some practical experience with chemistry. This experience and schooling may have aided these manufacturers to produce excellent emulsions, and, therefore, develop sizable businesses.

The introduction of dry plates in the United States initiated substantial changes in the character and structure of the American photographic industry. In 1879, at the time that the first dry plates appeared, there were only fifteen American companies manufacturing photographic materials and apparatus, but two firms accounted for forty per cent of the value of all products.[60] During the first decade of dry plate production, the value of output in the photographic materials industry increased nearly sixteen times.[61] During the period from 1880 to 1886 the number of dry plate manufacturers increased

60. Census of Manufacturers, 1880, II, 13.

61. Table 1.

from five to about eighteen. In the early 1890's there were about twenty-five producers; however, as film photography grew in popularity, the number of manufacturers declined slowly.[62] The periods of highest entry of new firms into the field of production were in the early 1880's and the early 1890's. Thereafter, the number of firms going out of business exceeded the new entrants.[63] Established producers had national reputations which gave them advantage over new entrants, and the cost of machinery and the initial expense of large-scale production made successful entry more difficult than it had been earlier. Therefore production again became increasingly concentrated in the hands of a few very large establishments. At the end of the century, however, it became clear that the mass market, the amateur photographers, preferred film photography; and, therefore, the potential for expansion of production in the dry plate field was greatly reduced.

Thus English amateurs were responsible for introducing gelatin emulsions and the production of gelatin dry plates. During the 1870's the English photographic journals made information on the new gelatin emulsions generally available, and this availability helped to stimulate plate production; later, as large-scale production emerged, new ideas were not as freely communicated,

62. Table 3.

63. Table 4.

and patents and trade secrets became more common than earlier. The initial lead of the English in dry plate production gave them an advantage in the world markets which was not overcome by other producers during the nineteenth century.

Although a number of English firms began production of plates, companies such as Ilford, Edwards, and Wratten and Wainwright emerged as the leaders in output, exporting plates to Germany and other countries of the world. In France the Lumière company grew rapidly in the last two decades of the century, gradually supplanting English producers in the French market. German producers remained relatively small, although by the end of the century large chemical establishments such as Agfa and Hauff had begun dry plate production. The German dry plate industry had difficulties in supplying plates competitively even to their domestic market because of their dependence upon English and Belgium plate glass and because of the high tariff they had to pay on this glass. Although American producers also had to import plates from England and Belgium, the comparative isolation from Europe allowed these producers to develop their domestic market. By the end of the century, plates from St. Louis and Rochester companies not only dominated the American market but had also found receptive markets in North and South America, Europe, and Australia.

During the last two decades of the century, the German dry plate industry had a closer relationship with science than did the companies in the United States, England, and France. Many of the leading German producers were either scientifically trained themselves or established laboratories in their factories and employed chemists or scientific consultants. This close association with science, which brought development of orthochromatic and panchromatic gelatin plates and a variety of new organic developers, could not, however, overcome or compensate for the problem of the plate glass supply.

At the end of the century several non-German European firms also had research laboratories, including Wratten and Wainwright and Ilford in England and Lumière in France. Therefore, the dry plate business had provided the financial base which allowed the establishment of research facilities and the employment of chemists. In the United States a few chemists were hired by the Seed and Eastman companies. Yet, in general, the association between American producers and science was very limited.

By 1900 it was becoming clear that films possessed a much stronger appeal to amateurs than did dry plates; and, therefore, the potential of the dry plate industry was severely limited by this new competitor. Already the number of dry plate producers was declining in the United States, and film photography was rapidly increasing in its

share of the total value of output in the materials industry. The dry plate provided the first step in the dramatic change in photography and the photographic industry in the last quarter of the century. The change from collodion-on-glass photography to gelatin-on-glass was wrought with difficulties because of the substantial increase in sensitivity. Yet, the gelatin plate quickened the interest of amateurs in photography and once again made possible the factory production of the photosensitive materials for cameras. Then one of these dry plate companies, building on the financial base provided by the dry plate business, introduced the second step in this change, film and the roll film camera. Once again photographers had to make an adjustment to a technological change, but this change brought for the first time a mass market to the photographic industry. With the large-scale entry of the amateur into photography, the relative importance of the dry plate dropped, and photographic materials production became a big business. At the same time, the financial success of large-scale production provided the financial base for the employment of chemists and the establishment of research facilities.

FILM PHOTOGRAPHY

The history of film photography started at the same point as the history of collodion photography, but because of the intricacies of making a suitable celluloid film, the birth of film photography was preceded by a forty-year incubation period. After a fundamental chemical discovery in 1846, amateurs and technicians conducted a variety of investigations which in about twenty years led to the introduction of celluloid, but it required another twenty years of trial-and-error efforts before a celluloid film suitable for roll-film photography was developed.

In 1846 Christian F. Schönbein, a professor of chemistry at Basel, you will recall, nitrated cellulose using nitric and sulfuric acids, and in a short time, he and other chemical investigators discovered collodion, the viscous liquid resulting from dissolving nitrocellulose in ether and alcohol. Photographers readily adopted collodion as an adherent for sensitive salts on glass, using the dissolved nitrocellulose in the fluid state. However, within a decade of Schönbein's discovery, other investigators began observing the properties of the collodion residue remaining after evaporation of the volatile solvents.

Alexander Parkes (1813-1890), an English chemist and engineer, developed about 1855 a hard transparent film by

dissolving nitro-cellulose in the alcohol and ether (both volatile solvents) and then evaporating the solvents. This substance was called Parkesine. The film was tough, but uneven evaporation sometimes made it brittle and produced an uneven surface. Parkes continued his investigation of nitrocellulose materials and in 1865 developed a material called xylonite, formed by dissolving nitrocellulose in alcohol, camphor, and castor oil. and allowing the volatile materials to evaporate. The addition of castor oil made the material more plastic than Parkesine. While Parkes abandoned further efforts at this point because of the uneven surface, a close associate, Daniel Spill, continued trial-and-error methods of improving the materials. In 1868 he made xylonite more flexible by increasing the quantity of castor oil in relation to the other solvents. In 1869 and 1870 he further discovered that an ethyl alcohol solution of camphor or acetaldehyde made an excellent solvent, producing a reliable plastic. He established the firm of Daniel Spill and Company for the production of the plastic for combs and windows of tents. In spite of substantial advances in the production of this material, evaporation still required a couple of days.[64]

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64. Goodwin vs Eastman, I, 496; Photog. N., XIV (1870), 608; Aaron J. Ihde, The Development of Chemistry (New York, 1964), pp. 711-712; Edward C. Worden, Nitrocellulose Industry... (New York, 1911), pp. 568-572. Note that the history of development and patents of celluloid materials is fully treated in Goodwin vs Eastman, I, 492-520, and in Worden's very detailed work.

John W. Hyatt (1837-1920), a printer in Albany, New York, turned his attention to plastics and in 1869 developed a nitrocellulose residue which did not require such long evaporation periods. Where Spill and Parkes used castor oil for plasticity, Hyatt found that by dissolving under high pressure nitrocellulose in a small quantity of solvent, the drying time was shortened and plasticity retained. In 1870 he began to use camphor, which he found improved the surface quality. Two years later he and his brother Isaiah formed the Celluloid Manufacturing Company, a firm which later became the Celluloid Company.[65] The celluloid was produced in blocks or relatively thick films which limited its use in photography to celluloid plates.

For many years photographers searched for a substitute for the heavy glass plates. When gelatin emulsions were introduced, Leon Warnerke tested the use of paper as a film, removing the emulsion from the paper prior to printing; however, the intricacies of the process discouraged its commercial development at this time.[66] In 1880 the Société photographique de France offered a substantial prize to the developer of a substitute for the glass plates in negatives, but the prize was withdrawn in 1883 when no suitable substitute had been presented.

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65. Worden, pp. 576-579.

66. Goodwin vs. Eastman, I, 495; see Brit. J. Photog., XXXII (1885), 601.

Some photographers such as Ferrier in Paris and Palmer in Liverpool developed gelatin and collodion substitutes in the early 1880's, but when these substances were damp, they expanded unequally, causing cracking of the film surface. Others such as Pumphrey of Birmingham, Morgan and Kidd of London, and Woodbury of London tried, like Warnerke, to make paper film but without removing the emulsion; however, the grain of the paper showed through on to the print.[67]

Though various journals and photographic organizations encouraged the search for a suitable substitute for glass during the early 1880's, there was little success at first. In Rochester, however, George Eastman was following these journals and keeping abreast of the efforts of others. He knew of the difficulties of the other experimenters because, as he said, "I made it my business to keep thoroughly posted in such matters."[68] Eastman himself began investigations of collodion-coated paper in 1884. Following the lead of Warnerke, he detached the dried film from the paper. He tried without success to make the film thicker than it was at first; nevertheless, as he later observed, "I was fully convinced of the desirability of such a film and was on the lookout from that time for something that I could get a heavy enough coating

67. Goodwin vs Eastman, I, 332, 348, and 508-515; John Carbutt, "Substitute for Glass," Photog. N., XXXII (1888), 806-807.

68. Goodwin vs Eastman, I, 322.

with."[69] Eastman was strongly enough committed to the idea of film photography in 1884 that he brought William H. Walker, an unsuccessful camera manufacturer, into the business primarily because of his development of a roll holder and a clock key feature for hand cameras.[70]

Failing initially in his efforts to produce a detachable paper-collodion film, Eastman turned to paper film. By treating good quality paper with vaseline, he made it semitransparent and used it as negative paper. Though the Eastman company soon began production of this paper film, it was not particularly popular. Next Eastman developed a paper-gelatin stripping film, based on the Warnerke idea. The film was rolled on a spool and placed in a camera. After exposing the film, the photographer returned the camera to the plant, where the film was removed, developed, and fixed. Then the gelatin emulsion was stripped from the paper base and attached to glass plates for printing. Because the final photograph was not printed through the grainy paper base but through a temporary glass base, this stripping film superseded paper film. Yet the process was a very delicate and expensive one. At first the roll holders were made to fit dry plate cameras, but the demand for film was small. Therefore

69. Ibid., I, 333.
70. Ackerman, p. 47.

a special roll film camera, the Kodak, was developed by the Eastman company. Kodaks went on the market in 1888 at a cost of twenty-five dollars each, including the cost of a one-hundred exposure roll of film, the developing, and the printing. The cost of additional film and processing was ten dollars per roll. During 1888 and 1889 the Eastman company reduced prices and did a modest business in paper stripping films, but these first Kodaks were not particularly popular.[71]

Eastman's development of film photography grew out of his efforts to find a substitute for glass and probably reflected a general interest among photographers at the time. His use of paper and detachable paper-gelatin film probably developed out of general ideas being considered and tested by others. Approaching the problems of photography by way of trial-and-error methods, Eastman demonstrated his genius, however, in recognizing the potential of certain ideas and making them practical for commercial production.

Still not satisfied with his intricate detachable paper-gelatin film, Eastman became intent on finding a better substitute for glass. Although he had gained

71. Goodman vs Eastman, I, 319-320, 329, 342, and 351; gross sales of flexible paper stripping film: 1888 - $15,000, 1889 - $20,000, Ibid., I, 362; Ackerman, pp. 45-47, 64, and 274; prices of Kodaks and stripping film came down by about half on the camera and four-fifths on the film - see American Annual of Photography...Almanac for 1888, xxxiii and xxxiv.

an excellent understanding of photographic chemistry, largely from the various photographic journals he read, he did not have the academic training in chemistry necessary to tackle the problem of producing celluloid film. Therefore, he hired Henry M. Reichenbach (b. 1863?) to work in his small company laboratory. Reichenbach had studied under Professor Samuel A. Lattimore and, after receiving his bachelor's degree in chemistry, had continued to work as an assistant to Lattimore in the newly established chemistry laboratory at the University of Rochester. Eastman had known Lattimore personally, and when he had decided he needed a chemist, he had asked Lattimore for recommendations. Reichenbach joined the Eastman company in the summer of 1886 and for a time carried out investigations on emulsions. Then, late in 1888, Eastman put Reichenbach to work trying to find a suitable celluloid film. Eastman's employment of Reichenbach represents one of the first cases of an American company hiring a chemist to do research.[72]

Eastman hoped to produce a celluloid film which, unlike those produced earlier, would be very thin and flexible and have a smooth surface which would not be damaged by the developing and fixing chemicals. In 1888 a sales representative of the Celluloid Varnish Company

72. Ackerman, p. 56; *Goodwin vs Eastman*, I, 334 and 349.

recommended a varnish to Eastman which he thought might replace the gelatin skin. Eastman passed the information on to Reichenbach with instructions to consider its use with nitrocellulose. Reichenbach worked on the problem in December, January, and February, 1888 and 1889, eventually producing a film by drying a solution of nitrocellulose and wood alcohol; however, the film had little strength and peeled from the glass on which it was poured. Then Reichenbach added camphor to the solvent solution in order to strengthen the film, but when more than half the solvent was camphor, the surface of the film began to crystallize upon drying. By using heat to evaporate the solvent, he could, however, avoid some crystallization; but the high temperature of the film made it difficult to apply the gelatin emulsion. Finally he tried adding various substances to the solvent solution and found that both fusel oil and amyl acetate deterred crystallization. Thus by March of 1889 Reichenbach had developed a satisfactory process for producing a thin film. He dissolved the nitrocellulose in a solution containing both high boiling and low boiling solvents of nitrocellulose. The high boiling solvents helped to prevent surface crystallization caused by too rapid evaporation, while the low-boiling solvents reduced the long drying periods caused

by too slow evaporation of the solution.[73]

After Reichenbach had developed a satisfactory celluloid film, he and Eastman drew up several patents and submitted them to patent attorneys for the company. Eventually three patents were granted to Reichenbach and Eastman for this new celluloid film. The Reichenbach formula called for a large quantity of camphor in the solution; however, the failure of the Eastman company to continue production by this formula later led to a very costly infringement suit.

Hence Eastman's employment of a chemist to develop a new thin film base for photography led to the discovery, practical development, and commercial exploitation of celluloid roll film as a carrier for photosensitive gelatin emulsions. Although Reichenbach held only a bachelor's degree in chemistry, his academic training combined with Eastman's practical experience and general acquaintance with the literature on photographic films was probably instrumental in this significant technical advance in photography. Reichenbach's work stands between the amateur trial-and-error methods of development in applied science areas and the more systematic and theoretical

73. Ibid., I, 30-42, 74, 323-324, and 360 (from testimony of George Eastman and Charles F. Chandler). The solvents used were: high boiling: fusel oil, amyl acetate, and camphor; low boiling: methyl alcohol; Ibid., I, 74.

approaches used by such investigators as Andresen, the Lumière brothers, and Seyewetz, all working at about the same time, and Sheppard and Mees conducting investigations shortly after the turn of the century. In this embryonic stage in the development of industrial research laboratories, it is difficult to draw the line of demarcation between the plant analytical chemist and the research chemist. To some extent early chemists employed in the photographic industry probably fulfilled both roles.

Eastman had followed Reichenbach's progress very carefully and, as success in development of celluloid film was in view, had designed the machinery required for its production. He had a factory building equipped for manufacture of long sheets of celluloid film and initiated a national advertising campaign for the new film and Kodaks in May of 1889, advertising in fifteen of the nation's leading magazines. Difficulties in making the transition from laboratory preparation to large-scale production delayed full operations until August, but when the new film reached the market, the reception was very enthusiastic.[74]

Originally, Eastman had aimed at professional and ardent amateur photographers in his advertising campaign,

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74. Ackerman, pp. 62-63; Goodwin vs Eastman, I, 342. The initial investment in production facilities was from $12,000 to $18,000 (Ibid., I, 342 and 346), while during the first 18 days of September, 1899, sales totaled $22,500 (Ackerman, p. 63).

but his philosophy soon changed.

> "When we started out with our scheme of film photography, we expected that everybody that used glass plates would take up films, but we found that the number that did this was relatively small and that in order to make a large business we would have to reach the general public and create a new class of patrons."[75]

It was the execution of precisely this plan that made the Eastman company during the next decade the largest manufacturer of photographic materials and apparatus in the world.

While demand and production rose very rapidly during the 1890's, Eastman continued to seek improvements in his products and his mode of production. In 1895 William G. Stuber, operator of a small dry plate factory in Louisville, came to Rochester, taking charge of the photosensitive emulsion department. In addition, he sold an emulsion coating machine and his own recipe for gelatin emulsions to Eastman.[76] Both of these items improved the quality of the Eastman film. In 1896 and 1897 Stuber developed emulsions for plates and paper specially sensitized for X-rays.[77] Meanwhile, Eastman continued to acquire companies, purchasing the Boston Camera Company in 1895 in order to obtain a new type

75. Goodwin vs Eastman, I, p. 353.

76. In 1924 when George Eastman passed control of the firm on to his successors, William G. Stuber became president of the Eastman company.

77. Goodwin vs Eastman, I, 352; Ackerman, pp. 107-108, 114, and 119; Wentzel, p. 261.

of film spool. Later, at the end of the century, Eastman also purchased the Blair Camera Company of Boston in order to obtain rights on the use of a daylight black paper backing on roll film which permitted the film to be loaded in daylight. Therefore, film once again became attached to paper, but only after becoming independent of paper as the carrier.

By the end of the century, the operations and production of the Eastman company had become very large. During the peak period of production in 1898, film was produced at the rate of 150 miles per week. A year later Eastman introduced a new continuous-flow film machine which both increased output and substantially lowered costs. One of the major factors in expansion of film production at the end of the century, in addition to the growing popularity of amateur film photography, was the introduction of movies. In 1895 both Edison and the Lumière brothers had demonstrated movies, utilizing celluloid film. By the end of the century the Eastman company was operating both the Rochester and Harrow film plants at full capacity in order to keep up with the orders. Certainly the cinema played an important role in stimulating the already rapidly growing film company.[78]

78. Ibid., pp. 257-258 (Note that Wentzel has the incorrect date for the introduction of the continuous-flow machine); Ackerman, pp. 121, 137, and 154-155; Goodwin vs Eastman, I, 429.

A few statistics illustrate the expansion of the Eastman operations. Employment rose from five in 1882 to more than three thousand in 1900. Between 1895 and 1900 annual earnings increased from about $850,000 to $7,000,000.[79] By the early part of the twentieth century the firm was America's largest private consumer of silver, using from four to five tons per month.

At the same time that Eastman was expanding film production, he was acquiring interests in other photographic firms and developing a world-wide sales and production organization. In 1901 the firm became the Eastman Kodak Company of New Jersey, combining the operations of Kodak, Ltd., London; Eastman Kodak Co., Rochester; General Aristotype Co., Rochester; Eastman Kodak Société Anonyme Française of Nice; and Kodak G.m.b.H. of Berlin. Initially this firm controlled nearly ninety percent of all film production and was the largest camera and paper manufacturer in the world.[80]

During this period of rapid growth, Eastman recognized the importance of science and scientifically trained

79. These figures are based on published earnings figures: Brit. J. Photog. LIV (1907), 293; and a pound-dollar conversion of $4.80/£; dollars adjusted to 1960 dollars based on wholesale price index. Therefore these figures are approximate but do indicate that the company was doing a good business in 1895 and in five years expanded earnings about nine fold.

80. Ackerman, pp. 178-179, 197, and 203.

personnel in the direction and development of the company's operations. Though many of his trained chemists were not doing theoretical work, a few were put on specific research projects. After Reichenbach had developed thin celluloid film, he continued to work on improved types of film and emulsions. Moreover, at about the same time that Eastman had hired him, Eastman had also employed Joseph Thacher Clarke of Boston as a scientific expert for Europe.

From an early date Eastman sought to recruit recent graduates from the newly developing science departments of leading American colleges and universities. In 1891 Eastman contacted Professor Thomas M. Drown, Richard Perkin Professor of Analytical Chemistry at Massachusetts Institute of Technology, seeking an assistant manufacturing chemist. Early in 1892, after the dismissal of Reichenbach,[81] he sent letters to Professor Ira Remsen of Johns Hopkins, Professor Charles F. Chandler of Columbia University, and the Chemistry Laboratory of Cornell University seeking another chemist. At that time he hired Dr. Leonard Paget to carry out research work for the company in New York City.[82]

Eastman not only turned to scientifically trained personnel for chemical laboratories or special research

81. He was accused of taking part in a conspiracy to set up a rival company.

82. Ackerman, pp. 56 and 90-91.

projects but also selected supervisors with scientific backgrounds. During the summer of 1890 he employed Darragh de Lancey, a mechanical engineer who had graduated from Massachusetts Institute of Technology. In a little over a year, this man became manager of the Kodak Park Works. Eastman hired Frank M. Lovejoy as superintendent of the film department in 1897, but when de Lancey fell ill in 1898 Lovejoy became assistant manager. Lovejoy had graduated as a chemical engineer from Massachusetts Institute of Technology just three years before. Within two years he became manager of the Kodak Park Works and later became President and Chairman of the Board of the Eastman company.[83]

Eastman himself spent considerable time in the small company laboratory, testing various emulsion formulas; but in the early 1890's when he built a new experimental laboratory at Kodak Park and added trained chemists to ~~his rapidly expanding company, he retired from the~~ laboratory. One of the chemists hired for this laboratory was James H. Haste, who had graduated with a bachelor's degree in chemistry from Massachusetts Institute of Technology. Haste carried out experimental investigations until 1898, when he became the superintendent of the newly established chemical plant at Kodak Park. Later he con-

83. Ibid., pp. 93 and 150-151; Goodwin vs Eastman, I, 29; III, 664; Photog. J., LXXXV (1945), 236.

ducted studies intended to develop a nonflammable film.[84]

Eastman was pleased with the engineers he had hired earlier and continued to recruit personnel from leading schools. Once when he was recruiting graduates from Sheffield Scientific School, Columbia School of Mines, Massachusetts Institute of Technology, and Purdue University, Eastman wrote to his partner and close friend, Henry A. Strong:

> "I am on the lookout for two new chemical engineers and have appointments with four or five recent graduates who are coming to see me. I intend to keep a good stock of of this material on hand."[85]

But, in addition, Eastman recognized the desirability of having research personnel and facilities. At the end of the century he endeavored to get Leo Baekeland to come to Rochester to work in the chemical laboratory at Kodak Park, but this effort failed. The Eastman research laboratory was expanded several times during the early twentieth century, culminating with the hiring of Dr. C. E. Kenneth Mees to direct the Kodak Research Laboratory in 1912 and the establishment of a permanent research staff including Mees's close associate, Dr. Samuel Sheppard. Thus it seems clear that George Eastman recognized the importance of science to the photographic industry, where scientific developments

84. Ackerman, pp. 95 and 98; Goodwin vs Eastman, III, 704–710.

85. Ackerman, p. 153.

and technological changes came rapidly. He sought scientifically trained personnel from an early period in the development of the firm and utilized their abilities in the plant, in the research laboratory, and at the supervisory level. His conscious recognition of the importance of research to his company is illustrated in his comment made in 1896: "I believe in experiments as much as anyone and in fact our entire business has been founded upon them..."[86] From the beginning, he recognized the importance of new ideas and their exploitation and increasingly utilized scientific facilities and personnel to institutionalize the process of innovation in photographic science and technology.

Though the Eastman company came to control a large part of the world film market, a few other firms in the United States and Europe made efforts to produce celluloid film. John Carbutt of Philadelphia purchased thick celluloid film from the Celluloid Manufacturing Company in 1884, coated it with his own emulsion, and marketed film plates which were substantially lighter than glass; however, the film was shaved from blocks of celluloid and could not be produced thin enough for rolling.[87] Carbutt and later, about 1890, the Blair Camera Company manufactured celluloid film plates for use in dry plate

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86. Ibid., p. 120.

87. Goodwin vs Eastman, I, 338; III, 782; Photog. N., XXXII (1888), 737.

cameras, but because of the Reichenbach and Eastman patents, these firms encountered difficulties in producing roll films.[88]

The Anthony company in New York considered film production at the beginning of the 1890's. Professor Chandler of Columbia University acted as a chemical consultant to the firm for many years. When Baekeland was employed by the Anthony firm, the company encouraged his investigation of film for use in photography, no doubt in response to the entry of the Eastman product on the market; however, after Baekeland left the company, little is heard of further efforts in film photography until the twentieth century. Therefore, at least one other American photographic firm recognized to some extent the importance of scientific personnel for its work, but it did not obtain and utilize such personnel to the extent that the Eastman company did.

At about the time Eastman was developing thin celluloid film, Reverend Hannibal Goodwin (1822-1900) of Newark, New Jersey, applied for a patent for thin celluloid films with photosensitive emulsions coated on them. There was considerable delay in the granting of his patent (granted in 1898). Shortly before Goodwin's death, a plant for

88. Goodwin vs Eastman, I, 379; III, 803-804; Ackerman, p. 126. The Celluloid Company of Newark also produced flowed film, and in the early 1890's it began supplying thin film to Blair, see Goodwin vs Eastman, III, 766-791.

production of such film was established, but it never produced film on a commercial scale. During the first decade of the twentieth century, a legal battle was fought between the Eastman and Goodwin companies. The latter company, which was owned by Ansco -- a merger of the old photographic supply companies of Anthony and Scovill --, sued the Eastman company for infringement of the Goodwin patent. Because the Eastman firm had changed its formula in 1891 and no longer used the camphor called for in the Reichenbach patent, the judge ruled in favor of the complainant. The suit was settled for five million dollars.[89]

In Europe variations in patent regulations made it possible for other companies to manufacture thin film, but these companies accounted for only a small portion of total production during the nineteenth century. In Great Britain dry plate firms such as Ilford, Sandell, and Edwards moved into film production. But these and a number of smaller companies which concentrated on film plates rather than roll film were overwhelmed by the production facilities of the Eastman film plant at Harrow.[90] The Eastman company had established offices in England about 1885 and began production of film in 1891. During the 1890's the company also operated a small research labora-

89. Ibid., I, 384-385; Taft, pp. 400 and 508.

90. Goodwin vs Eastman, I, 423; Brit. J. Photog., LIV (1907), 11; Photog. N., XL (1896), 222.

tory in connection with the production facilities at Harrow.[91] At Lyon the Lumière company began manufacture of celluloid film for use in its movie cameras; however, the production of cameras and film amounted to less than 10 per cent of total output in 1899 and 1900.[92]

In Germany during the last decade of the century some effort was made to produce thin celluloid film for photographic purposes. Agfa and Schering, both in the photographic chemical dye business, tried to produce roll film in the late 1890's but after a short time ceased production because of their inability to compete with the superior American product.[93] Early in the twentieth century an improved celluloid film was developed in Andresen's laboratory, and Agfa resumed film production, becoming a major producer during World War I.

Therefore, at the end of the century the Eastman company had a virtual monopoly on the world's production of thin, rollable celluloid film. Because of the nature of celluloid film production, a number of advantages accrued to this company which, once manufacture was begun, helped it to maintain their dominant control of this phase of production. First, because it was the first company to produce film, because it maintained standards of quality and guaranteed its products, and because of

91. Ibid., XXXV (1891), 151; Ackerman, p. 120.

92. Eder, "Ein Besuch...," Photog. Korresp., XXXVIII (1901), 83.

93. Photog. Korresp., XXXVII (1900), 276; Kühn, p. 57.

its international advertising campaigns, the Eastman company was well-known and trusted by the public at large. Second, since the company had acquired the patents and a fund of technical knowledge about production of thin celluloid film, it was difficult for potential competitors to produce as good or better film than Eastman. Third, production and research chemists continued to improve the quality of the film. Fourth, the machine technology for large-scale production required substantial capital for expensive machinery and long and costly production experiments. Fifth, even if a company were to produce a competitive film, few companies had the experience with or chemical knowledge of the photosensitive emulsions required to produce photographic film.

The increasing capital costs for manufacture of photographic materials is reflected in some of the statistics on the American photographic materials industry during the period 1880-1900. The concentration of production is indicated by the rise in value of product per establishment.[94] Yet, while the rising average capital per establishment shows that, increasingly, in order to be a producer in the industry one had to have substantial capital, it does not reflect changes in capital requirements due to introduction of sophisticated machinery,

94. Table 7.

processing, and laboratories.[95] However, the increasing average capital per value of product rise from 1879 to 1899 does demonstrate such increasing capital requirements.[96] The slight down-turn from 1899 to 1904 may reflect Eastman's introduction of the continuous-flow film producing machine, which sharply increased output and cut plant as well as production cost.

Therefore, the Eastman company was the first commercial establishment to produce thin photographic films, and it moved quickly to produce them on a large scale. It very soon was in a position which could be threatened only by an experienced dry plate firm which had and was willing to sacrifice substantial capital, with the attendant risk that its effort might fail for lack of scientific or technical knowledge.

In general, those companies that made any serious effort to develop or produce thin celluloid film for photographic purposes were producers of gelatin dry plates. By the early twentieth century a number of firms had experimented with production of film; yet it was only those companies which demonstrated a close association with chemistry and scientifically trained personnel, namely Eastman, Lumière and Agfa, that had made any commercial success of their efforts.

95. Table 6.

96. Table 8.

Chapter VII

PHOTOGRAPHIC PAPER PRODUCTION

With the introduction of negative-on-glass photography in the late 1840's and early 1850's, the need for positive printing papers sharply increased. After Blanquart-Evrard's introduction of albumen paper in 1850, this paper became the principal printing paper, superseding salted starch and gelatin papers. Initially, German producers became the world leaders in the manufacture of photographic papers. In the beginning, the German companies that became commercially successful were, in large part, those with scientifically trained personnel. Changes in photographic paper technology late in the century brought American producers into leadership in the world market. Again scientists and technically oriented businessmen combined to exploit both technical and business opportunities in order to triumph over the older and better established German producers.

GERMANY

In the early 1860's, a number of German photographers experimented with albumen paper and began commercial production. One of these experimenters was Dr. August Trapp (b. 1837), who had worked as an apothecary in Germany and Switzerland and had assisted in the laboratory of the famous chemist, Karl R. Fresenius (1818-1897) in Wiesbaden. Trapp had studied chemistry under Bunsen

at Heidelberg and Liebig at Munich, taking his degree at Giessen. In 1861 he established a chemical laboratory in a brewery in Friedberg and soon began production of photographic chemicals such as silver and gold salts, raw and iodized collodion, and liquid egg whites. During 1862 and 1863 he conducted experiments with egg whites in an effort to produce a good albumen paper. Progress came slowly, but in 1865 he established an albumen paper factory near his laboratory. In the late 1860's he took some relatives into the firm, and the firm name became Trapp und Münch. During the late 1860's and early 1870's the production and reputation of the firm grew rapidly.[1]

Another early investigator was Paul Eduard Liesegang (1838-1896). He studied both mathematics and chemistry at Vienna, Berlin, and Giessen, obtaining his doctoral degree in chemistry at Rostock. During the 1850's he became interested in photography and soon established a studio at Elberfeld, near Düsseldorf. During the late 1850's or early 1860's he established an albumen paper plant at Elberfeld but in 1873 moved his operations to Düsseldorf. In addition to his production of albumen paper, he operated a chemical plant at Bilk, near Düsseldorf, and a photographic apparatus company at Düsseldorf. Besides conducting his experimental work and business, Liesegang published articles in photographic

1. "Trapp", Photographische Korrespondenz, XXXXVIII (1911), 305-307.

journals and several books.[2]

Other early German producers of albumen paper included Dr. A. Kurz and Ernst Schering. Kurz began production of negative collodion and albumen paper at a plant in Wernigerode in 1864. A year later Schering established a division of his Chemische Fabrik auf Actien vorm. E. Schering which was devoted exclusively to the production of albumen paper.[3]

It is striking that three of the four early manufacturers held technical doctorates; two of the four were known to have studied or worked in the leading schools and laboratories of Europe. Schering, who did not have the doctorate, did have a good knowledge of chemistry and continued to work in the chemical laboratory of his company for many years. Therefore it seems clear that the initial producers of photographic paper in Germany brought to their enterprises substantial scientific training.

By the early 1870's, a number of albumen paper producing firms had been established in Dresden, and soon Dresden became the world's center for production of albumen paper. In 1874 seven Dresden photographic paper

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2. British Journal of Photography, XXXIV (1887), 746; J. C. Poggendorff, Biographisch-literarisches Handworterbuch zur Geschichte der exacten Wissenschaften (Leipzig and Berlin, 1863-1962, Vol. III, Part I (1858-1885), pp. 812-813.

3. Willy Kühn, Die photographische Industrie Deutschlands... (Schweidnitz, 1929), pp. 14 and 60; Erich Stenger, The History of Photography..., trans. E. Epstean (Easton, Penna., 1939), p. 90.

firms merged to form the Vereinigten Fabriken photographischer Papier A.-G. and, thereby, to control a very large portion of the total production of albumen paper.[4] In addition, this new firm obtained a contract from Blanchet Frères et Kleber in Rives, the producers of the best stock paper for photography, granting to the Dresden firm sole rights to the output of the Rives factory. By obtaining this contract, the Vereinigten Fabriken succeeded in a short time in securing a very large part of the total market.[5] This was not to be the last time that a major producer of photographic paper attempted to control production by gaining exclusive rights to the specially prepared raw paper.

Shortly after this merger, interest in photography began to grow rapidly because of introduction of gelatin dry plates. This increased interest was accompanied by substantial growth in production. In 1875 Vereinigten Fabriken produced between eight and nine thousand reams of albumen paper, while by 1889 output had increased to nineteen thousand reams.[6] This growth came in the face

4. The seven were: Sulzberger und Mater; Georg Wachsmuth und Co.; H. Anschütz; J. Fessler; W. Hoffmann und Co; Georg Rotter; Zinkeisen und Richter. See Kühn, p. 114.

5. Ibid., pp. 114 and 167.

6. Brit. J. Photog., XXI (1874), 193: Based on the estimate of eggs required to albumenize a ream of paper, about 300 eggs/ream; of course it must be understood that no account of variation in size of paper is taken here, and, therefore, chance for error is large. The consumption of eggs must have been near 2½ million in 1875 and 5½ million in 1889. Trapp und Münch produced in excess of 25,000 reams of albumen paper from 1863-1875; three years of production figures are available: 1867: 400 reams; 1868: 1524 reams; and

of two forms of competition. First, new firms began to appear in spite of Vereinigten's efforts to control the supply of raw paper. In Dresden at least five new producers appeared between 1874 and 1885.[7] These joined to form the Dresdener Albuminpapierfabrik A.-G. in 1885. This firm also obtained its raw paper from Blanchet Frères and Kleber; therefore, the efforts of the Vereinigten Fabrik to control the raw paper supply apparently had failed, and this failure permitted the Dresdener firm to emerge as one of the leading albumen paper manufacturers. Other producers outside of Dresden also appeared. For example, Dr. E. Just, a chemist, established in Vienna in 1880 a factory for production of photographic paper, specializing in albumen paper from 1880 to 1883. Second, new kinds of positive printing papers began to attract popular attention. From the late 1880's, albumen paper assumed an ever smaller portion of the market until the end of the century.[8]

One of the earliest important alternatives to albumen paper was collodio-chloride emulsion paper, which came to be popularly known in Germany as celloidin paper or

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1869: 2715 reams. Production increased rapidly for Trapp und Münch in the period 1863 to 1875 and for Vereinigten from 1875 to 1889. For figures see Photog. Korresp., XXXXVIII (1911), 305f.

7. The five firms were: Dresdener Albuminpapierfabrik A. F. Silomon; Stalling und Martin; H. Sander und Co.; E. Kader; and Unger und Hoffmann. Kühn, p.114.

8. Ibid., p. 61; Joseph M. Eder, History of Photography, trans. E. Epstean (New York, 1945), p. 781 (notes); H. and A. Gernsheim, The History of Photography...(London, 1955), p. 288.

aristotype paper. Shortly after Sayce and Bolton's publication in 1864 of their report on production of collodion bromide emulsions for negatives, George W. Simpson (1825-1880) published an account of his use of a collodio-silver-chloride emulsion for the sensitive coating on positive paper.[9] J. B. Obernetter of Munich began production in 1867,[10] and such paper was produced throughout the remainder of the century by a number of German firms. Celloidin papers, like albumen papers, were printing-out photographic papers, but they were both more sensitive and more permanent than the albumen types. Albumen papers remained in high demand, however, because difficulties in production limited the output of celloidin papers until the success of the firm of Dr. A. Kurz in about 1888. At that time Kurz switched production from hand coating to machine coating and, therefore, was better able to meet the demand.[11]

Other German firms also produced collodion papers. Rheinischen Emulsionspapierfabrik Heinrich Stolle in Köln-Ehrenfeld, a merger of a factory founded by Wandrowsky and Antonetty in 1893 in Köln-Ehrenfeld and the Emulsions Albuminpapier Fabrik A.-G. in Köln, was producing collodion papers by the end of the century, as also was the celloidin

9. Bolton and Sayce, Brit. J. Photog., XI (1864), 183; George W. Simpson, Photographic News, VIII (1864), 327.

10. Stenger, p. 49 claims 1867 and Gernsheim, p. 284 claims 1868.

11. Kühn, p. 61.

paper factory of Dr. Opitz in Munich.[12] Another producer was Walter und Münch in Karlsruhe.[13] The large albumen paper producers in Dresden, Vereinigten and Dresdener, also included these papers in their production. In 1894 they completed a pooling agreement whereby they consolidated administration of the two firms and distributed profits based on the ratio of capital of the two companies. As had earlier companies, they negotiated an exclusive contract for Rives paper, with the apparent intention of forcing the smaller photographic paper producers out of business and then reaping monopoly profits off the increased prices. Furthermore, they made agreements with the three German baryta coating firms stating that only paper destined for the Dresden plants was to be coated. Though these efforts succeeded for a time, in a short while new producers of paper and new baryta coaters emerged, and such firms as Walter und Münch and Rheinischen were able to persist.[14]

In Vienna Professor Ferdinand Hrdlička (b. 1860), a chemical engineer who taught at the Graphische Lehr-und Versuchanstalt, established a paper factory in 1893 and soon began production of collodion papers.[15]

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12. Fritz Wentzel, Die Fabrikation der photographischen Platten, Filme und Papiere und ihre maschinelle Verarbeitung (Halle, 1930), p. 391.

13. Photog. Korresp., XXXVII (1900), 105.

14. Ibid.; Kühn, pp. 114-115.

15. He was called to the Graphische Lehr-und Versuchanstalt by the Director of the technical school, J. M. Eder. See Eder, p. 779.

Though numerous firms included collodion-emulsion paper in their production, the difficulties in production and the problem of excessive stickiness which easily damaged the photographic image hampered its availability and popularity. Therefore, albumen paper remained very popular in the 1880's without serious competition from collodion paper. The advent of gelatin emulsions, however, signaled the gradual substitution of gelatin paper for albumen papers.

The introduction of gelatin as the binding agent for dry plates also brought the use of gelatin emulsions for printing paper. By using gelatin silver bromide emulsions for coating paper, photographic paper producers increased the sensitivity of their product. The use of gelatin made possible the introduction of developing-out papers. Yet the increased sensitivity of such papers was not an unmixed blessing. The extra precautions in handling and storing developing-out papers as well as the inability of the photographer to control visually the period of exposure for printing acted as deterrents in the adoption of such papers. Therefore, even though knowledge of the means of producing developing-out papers existed from the early 1870's, such papers were not widely popular until the late 1890's.

In Germany, where printing-out papers were first produced on a large scale, manufacturers were slow to add developing-out papers to their lines. This may have been

because the large establishments had investments in machinery and processing equipment for albumen paper. Because of this lag in production of developing-out papers, Germany had lost its position of dominance in the production of photographic paper by the end of the century.

In spite of German reluctance to produce developing-out papers, several manufacturers did initiate production of gelatin silver bromide papers. One of the very earliest producers was Dr. E. Just of Vienna, who, after producing albumen paper for three years, began production of gelatin bromide paper in 1883. Ten years later another Viennese paper manufacturer, Professor Hrdlička, also began production. In the late 1880's or early 1890's, Dr. Franz Stolze (1830-1910), a professor of shorthand at the University of Berlin, who was also very much interested in chemistry and physics, started small-scale production of gelatin bromide papers in Berlin. As late as 1894 Stolze produced only about 100 meters of paper per week. In 1894 Arthur Schwartz, a professional photographer who had worked in London and New York, founded in Berlin the Neue Photographische Gesellschaft, an establishment for large-scale printing of photographs. Finding gelatin bromide paper in short supply, Schwartz erected his own paper factory, which began production in 1895. He equipped the plant with machinery built in the United States. By the end of the decade, the firm had

become incorporated and had established branches in Rueil (Société Photographique) and London (Rotary Photographic Company). Later, another branch was established in Milan (Compagnia Rotografica).[16]

At the end of the century, additional German firms began producing gelatin bromide papers. These included Schering in Berlin, Dr. Riebensahrn und Posseldt in Berlin, Liesegang in Düsseldorf, Schaeuffelenschen in Heilbronn, and Rheinische Emulsionspapierfabrik A.-G. in Köln.[17]

At the time that gelatin developing-out papers were gradually gaining inpopularity during the last quarter of the nineteenth century, gelatin printing-out papers were introduced. Abney in England in 1882 produced a gelatin chloride printing-out paper, and by 1884 Emil Obernetter in Munich had introduced this paper as "Aristo" paper. In 1886 Liesegang in Düsseldorf also marketed this paper as "Aristotypie" paper. In 1885 Joseph Barker of London suggested subsequent toning with gold solution in order to make prints more permanent. Shortly, Obernetter introduced commercial papers requiring subsequent toning. Because of their low sensitivity, these printing-out papers had an advantage over the more sensitive gelatin bromide

16. Wentzel, p. 390; Eder, pp. 440-442, 453, and 779-782.

17. Wentzel, p. 390.

developing papers.[18]

In 1881 J. M. Eder and G. Pizzighelli in Vienna introduced a gelatin chloride developing-out paper which was somewhat intermediate in speed between the regular chloride and bromide papers. After learning of the process from the lectures of Eder and Pizzighelli at the Photographic Society of Vienna, Dr. E. Just in 1882 began production of this type of printing paper. Eder and Pizzighelli also directed how Just should set up his production. The advantage of this paper over other developing-out papers was the lower sensitivity, which permitted less care in protecting unexposed paper from light. In 1883 Eder also described a sensitive gelatin developing-out paper which utilized a combination of silver chloride and bromide in the emulsion. In the early 1890's, Liesegang began production of this paper and marketed it as "tula" paper. At about the same time Neue Photographische Gesellschaft in Berlin marketed it as "lenta" paper.[19] Gaslight papers, or developing-out papers which could be handled in artificial light without destroying their sensitivity, were produced by a few German firms after the turn of the century.

By 1900 photographic paper producers in Germany

18. Brit. J. Photog., XXXII (1885), 150; Photographic Journal, XXVII (1882), 155; Wentzel, p. 390; Stenger, p. 50.

19. Eder reports upon this personal relationship with producers in his History..., pp. 446-448. Partial confirmation is in Photog. N., XXVII (1883), 98.

faced over-production and very stiff competition, especially from the United States and France. They had lost their commercial dominance of the field. As a result, a number of companies merged, and soon many of the competing companies formed pooling agreements and apportioned the market according to their sizes.[20]

In summary, in the 1860's men well-schooled in chemistry established the first large-scale production of photographic goods, and they maintained their position of dominance until the late 1880's, when the new gelatin papers began to triumph. The various efforts to control the supply of raw paper encountered difficulties, and the loss of this control to an American producer in the late 1890's brought serious repercussions to the German producers. As a result of this foreign competition, the German industry once again established pooling agreements and apportioned the market. The role of science and science-trained personnel became less clear late in the century. Because of the large-scale nature of the operations and the complexity of the marketing and pooling agreements, management came increasingly into the hands of the professional organizer. During the infancy of the industry, when scientifically-trained personnel were intimately concerned with the business, the industry in Germany was very vigorous, but at the time of the rapid change in technology late in the century, the industry

20. Kühn, p. 106.

appeared sluggish and unable to adapt readily to the changing character of the market.

GREAT BRITAIN

The relatively low interest in photography in Great Britain during the 1840's was followed by high interest in the new negative-positive processes appearing in the early 1850's. When it was established that the Talbot patents did not apply to the glass negative processes, the field was open to commercialization of photography on a scale similar to that in France, Germany, and the United States.[21] About mid-century William Henry Fox Talbot and Thomas Sutton established positive printing firms at Reading and Jersey, respectively. About 1855 Blanquart-Evrard abandoned his company at Lille and joined Sutton, bringing with him his own process for production of albumen paper. The albumen process appeared to be a partial answer to the concern about permanency of photo-~~graphic prints, a concern which led to the nomination~~ of a committee of the Royal Photographic Society in London to study the problem and which in France led to the establishment of a prize of 2,000 francs by Duc de Luynes for the invention of permanent prints. Sir David Brewster carried out tests on Sutton's prints and declared that they were fairly permanent. Permanency remained a problem,

21. Talbot relaxed his patent restrictions in 1852 after requests from the Presidents of the Royal Society and the Royal Academy. During the summer of 1854 the jury in the trial Laroche vs Talbot concluded that Talbot's calotype patents did not extend to the collodion process.

however, throughout the remainder of the century.

Commercial production of positive printing paper began in the 1850's in Great Britain. John Sanford produced albumenized paper as early as 1855. At that time he also handled two other English papers as well as one French paper for his photographic trade. He continued to produce his paper on a commercial scale at least until the early 1870's. In 1861 London counted fifteen photographic paper producers, several of which were albumen paper producers. In the 1860's J. A. Spencer of London was the largest manufacturer of albumen paper in Great Britain. In 1866 Spencer's plant consumed 2,000 eggs daily. This would indicate that Spencer's production far exceeded that of Trapp und Münch in 1867, but the production of Vereinigten in 1875 far exceeded Spencer's 1866 figures. Spencer obtained a large part of his paper from Rives. Therefore, in the 1870's the combination of difficulties in obtaining raw paper, as a result of the restrictions imposed on Rives by Vereinigten of Dresden, and the new attention to Swan's carbon printing process probably brought a decline in the relative importance of Spencer's production of albumen paper.[22]

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22. Humphrey's Journal, VII (May, 1855), 12 (ad); XIX (1867), 77; Photog. J., XIV (April 17, 1869), ii (ad); (December 18, 1869), i (ad); John Werge, The Evolution of Photography (London, 1890), pp. 102-103; Gernsheim, pp. 270-272.

There were, of course, other important producers of albumen paper in Great Britain during the 1860's. J. Skinner established the Scottish Albumenizing Company in Glascow in the early 1860's and remained there for four or five years. When he encountered difficulties with his egg supply, he transferred operations to London and changed the name of the firm to the Albion Albumenizing Company. In London the trade increased rapidly, with the consumption of eggs reaching more than one thousand per day in 1873. This consumption would indicate that Albion's production was about one-fifth that of Vereinigten's in Dresden. Like Spencer, however, Albion depended upon Rives paper and, therefore, was strongly affected by the formation of the Dresden union of paper manufacturers in 1874.[23]

In spite of George W. Simpson's initial suggestion of producing collodion-chloride emulsion paper in 1864, British photographic paper producers did not respond. While manufacturers in Germany did initiate such production before the end of the decade, it was not until about 1880 that a major English producer appeared.[24]

In 1873 William Willis (1840-1923) patented and commercially introduced platinum paper. The Platinotype Company was established in 1879 and continued in operation late into the century. Platinum paper produced

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23. Brit. J. Photog., XXI (1874), 193-194.

24. B. J. Edwards and Company in Hackney. Photog. N., XLI (1897), 847.

very beautiful and permanent prints, especially after modifications in the process were announced by Pizzighelli and Hübl in 1882. Rapidly increasing prices of platinum metal, however, forced photographers to all but abandon its used by the end of the century.[25]

The idea of using gelatin silver bromide emulsions on paper originated with the Englishman Peter Mawdsley. In 1873 he operated the Liverpool Dry Plate and Photographic Printing Company, where he initiated production of gelatin bromide paper for commercial use without patenting the process. Mawdsley proceeded to describe his work in the <u>British Journal of Photography Almanac for 1874</u>. There was not, however, a great demand for this new paper, due in large part, probably, to its high sensitivity and different method of use. While some amateurs tried Mawdsley's papers, professionals were indifferent to them. Consequently, gelatin papers did not become popular until later. By 1879 Mawdsley had moved to London but had discontinued production of gelatin papers. In 1879, however, Joseph W. Swan, who had manufactured photographic materials since the middle 1850's, patented in England (#2968) gelatin bromide printing paper and soon began commercial production.[26]

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25. <u>Photog. N.</u>, XXXVII (Feb. 3, 1893), IX (ad). Gernsheim quotes English platinum prices: 1878-25s; 1891 - £3; and even higher in early part of twentieth century, p. 283.

26. Swan, pp. 44 and 29.

W. T. Morgan and Co. (later Morgan and Kidd) of London also began production of gelatin bromide paper at this time. This firm claimed to have made such paper from 1874 and, during the 1870's and early 1880's, was the leading English producer. It also established the first large scale printing and enlarging service for amateurs.[27]

During the 1880's and 1890's other English producers of gelatin papers appeared. B. J. Edwards, a professional photographer of Hackney, began production of dry plates in 1878 and in the 1880's produced both collodion and gelatin chloride papers. Only a year after Eder's announcement of gelatin chloro-bromide paper, Marion and Co. of London began production of this developing-out paper. Britannia Works (later Ilford) in London started production of this paper in 1887. Other English producers of gelatin developing-out papers included Wellington and Ward at Elstree, Thomas Illingworth in London, Barret Dry Plate Factory outside of London, Imperial Dry Plate Co. in London, and Cadett and Neall of Ashtead. It would appear that many dry plate producers in England extended their operations to developing-out papers, utilizing the same basic emulsion for both.[28]

27. Gernsheim, p. 285; Eder, p. 440.

28. Photog. N., XLI (1897), 767 and 847; XLII (1898), 154; Brit. J. Photog., XLVII (Jan. 5, 1900), 12; LIV (July 26, 1907; Suppl. 4), 646 and 679; Wentzel, pp. 389-390.

The first formula for gelatin chloride printing-out paper was, of course, published by Captain Abney (1843-1920) in 1882.[29] By the late 1880's English firms had taken up production of this paper. The Birmingham Photographic Company initiated production, but in 1891 Britannia also began production. The Imperial Dry Plate Co. of London also produced it in the 1890's.[30] After the publications of Eder and Pizzighelli in 1881, Leon Warneke in 1889 initiated production in England of their gelatin chloride developing-out paper. Such paper, however, did not become popular until the introduction of modifications by Baekeland in 1893, after which Velox gaslight papers became popular.

In summary, in the 1860's England was in a strong position in the production of albumen paper, but by the 1870's Dresden had eclipsed England as the leader in production of positive printing paper. With the development of dry plate emulsions in England, however, a number of firms also used similar emulsions to produce gelatin developing-out papers and put England in the fore in their production in the late 1870's and 1880's. During that period, however, albumen printing paper still remained the most popular photographic paper. England's producers, in contrast to those in Germany, were people

29. Photog. J., XXVII (1882), 155.

30. Brit. J. Photog., LIV (1907), 930; Photog. N., XL (1896), 317.

relatively untrained in science. Some of the ideas for improvements in printing paper came from scientifically trained people such as the Germans Eder and Pizzighelli, but these ideas were implemented by businessmen-mechanics. Through the early 1880's new ideas for emulsions and coatings still appeared in the photographic journals; however, the free flow of information was already on the decline as evidenced by Willis's patent on platinum paper and Swan's patent on gelatin bromide emulsion. Increasingly, as firms came to greater prominence in photography, they held a vested interest in new ideas, and, therefore, important formulas and ideas of potential commercial significance were not freely published.

FRANCE

The German photographic paper industry was initially in a strong position but then encountered stiff competition by the end of the century; in France, significant growth came only in the last decade of the century. This occurred in spite of the excellent source of raw paper from Rives.

In the period prior to the 1890's, a few establishments produced photographic paper, but these consisted principally of large printing establishments rather than commercial producers of paper. In the early 1850's Blanquart-Evrard established and operated for a few years a photographic printing company at Lille. Utilizing Blanquart-Evrard's

photographic processes, forty part-time employees produced positive prints for amateurs and for book publishers. Another enterprising Frenchman, André Adolphe Disderi (1819-1890), patented carte-de-visite photographs in 1854 and opened establishments for their production all over Europe. By 1861 he had the reputation of being the wealthiest photographer in Europe, with an income of £48,000 in one year from his Paris establishment alone. These and other smaller shops produced and used albumen papers; however, their production was of little significance in terms of the world output.[31]

Later in the century, E. Lamy introduced gelatin silver bromide paper to France and initiated commercial production in 1879. He erected a factory at Courbevoie (Siene), but the company did not become a significant paper producer.[32]

In 1892 a major French photographic paper producer emerged with the establishment of a paper division by Société des Plaques Lumière (A. Lumière & ses fils in Lyon).[33] Antoine Lumière and his two sons, the photochemists Auguste and Louis, had established in 1883 a dry plate factory.[34] Following their initial success in dry

31. For example, M. Braun at Dornack on the Rhine. See: Brit. J. Photog., XXI (1874), 509; Gernsheim, pp. 144 and 224-225.

32. Eder, p. 440.

33. Agenda Lumière (Lyon, 1911), p. 3.

34. There is some uncertainty about the founding date. Agenda Lumière, p. 3, indicates the date as 1883. Yet

plate production, they expanded their production to photographic paper in 1892. They produced both gelatin bromide developing-out paper and gelatin chloride printing-out paper ("Aristo") on a large scale. By the end of the century, ten machines coated about 4500 meters per day (3/4 meter width). Paper production of Lumière, one of the world's largest photographic materials producers, comprised more than a quarter of the total value of output of the firm and exceeded two million francs.[35]

Late in the nineteenth and early in the twentieth century, other smaller French firms began production of photographic paper.[36] One of these was Société An. des Plaques Pellicules et Papiers Photographiques J. Jougla in Paris. Early in the new century this firm merged with that of Lumière.[37]

Thus France did not emerge as a leader in the production of photographic paper until late in the nineteenth century. Furthermore, French producers were not innovators in this field. The most important producer,

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Wentzel, p. 15, and Eder, p. 432, indicate 1882 as the date. The Lumière publication date is taken as the more reliable.

35. Joseph M. Eder, "Ein Besuch in der Trockenplattenfabrik von A. Lumière et fils in Lyon," Photog. Korresp., XXXVIII (1901), 73-83.

36. Such firms include: Grieshaber, frères & Co., Saint-Maure (Seine); La Société Industrielle de Photographie, S. A.; Rueil (S. u. O.) und R. Guilleminot; and Boespflug & Cie, Paris. See Wentzel, p. 391.

37. Kühn, p. 142.

Lumière, did, however, enter upon production of gelatin emulsion papers at the time of growing popularity of the new paper and, therefore, at a time when it was easy to capture the new market for these papers. Though there is no specific evidence pointing to a close link between scientists or scientific institutions and the production of photographic paper in France, it is nevertheless clear that the Lumière brothers were photo-chemists and certainly in a position both as decision makers and engineers to aid in the successful entry of the Lumière Company into this area of manufacture.

UNITED STATES

In the United States the daguerreotype was, of course, very popular, especially during the early 1850's. Production of daguerreotypes continued into the 1860's, but the cheaper tintypes (or ferrotypes) captured much attention in the decade 1855-1865. Until about 1860 the negative processes were not especially popular in the United States, and when they were used, photographers employed salted paper. In the early 1860's albumen paper came to the attention of American photographers.[38] During the Civil War the *cartes de visite* photographs, which were printed on albumen paper, became very popular. At this time *Humphrey's Journal* reported that "the card

38. *Hump. J.*, XIII (1862), 304; XV (1863), 96; Werge, p. 203.

photograph has for the past two years been in universal demand, almost to the complete exclusion of every other style of photographic portraiture...(it) has in fact produced a revolution in the photographic business...(with) proportional increase in the sales of albumen paper..."[39]

The firm E. and H. T. Anthony and Co. of New York, which held certain important American patents on card manufacture, benefited substantially from the revolution. By the summer of 1863 the Anthony company had established a factory for the production of albumen paper. During the early 1860's Anthony imported at least 15,000 reams of raw paper from France and Prussia, no doubt from Rives and Malmedy. In 1865 this firm employed one hundred workmen and girls in the manufacture of albumen paper. Therefore, the Anthony company secured a firm position in the American market for its albumen paper, a position which it retained until the late 1880's,[40] though of course it faced competition from the Dresden firms.

In the middle 1880's manufacture of gelatin bromide papers began. The Eastman Dry Plate Company began production of gelatin bromide paper in 1884. Much of Eastman's initial interest in paper production involved the production of a paper film for negatives. As a by-product, however, the

39. Hump. J., XV (1863), 12 and 32.

40. Oliver W. Holmes, The Atlantic Monthly, III (1859), 738; VIII (1861), 13; XII (1863), 1; see esp. XII (1863), 1-2; see also, Brit. J. Photog., XLVII (1900), 262.

Eastman company began commercial production of photographic paper in the middle 1880's. At about the same time T. C. Roche of the Anthony company also worked out a manufacturing process.[41] Eastman, however, made a commercial success of the new product by utilizing mass production methods. In 1885 he employed for the first time an automatic coating machine. As a consequence, there was a saving over hand-coated paper of 95% in labor and 25-50% in materials[42] The Eastman company obtained its raw paper from Steinbach of Malmedy, Prussia, and its chemicals from Anthony.[43] Soon, however, the contracts between Eastman and Anthony were terminated because of claims and counterclaims with regard to stealing each other's trade secrets with respect to photographic paper manufacture.[44] This difficulty in the late 1880's left relations strained between the two companies thereafter. Though the original problems were

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41. Taft, p. 390.

42. The Goodwin Film and Camera Company vs Eastman Kodak Company, United States District Court of Western New York (Buffalo, New York), Vol. I, p. 319; Carl W. Ackerman, George Eastman, p. 72.

43. Ibid., pp. 54-55; "United States vs Eastman Kodak Co.," The Federal Reporter, (St. Paul, 1916), CCXXVI (Nov.-Dec., 1915), 62-79.

44. Ackerman, pp. 71-73; Taft, p. 391.

settled out of court, in the twentieth century court suits were prosecuted by both sides.

During the late 1880's and the 1890's the Eastman company aggressively pursued the manufacture and marketing of photographic paper. By 1889 large scale production of paper was carried on at both the Rochester and Harrow, England, plants. In 1892 the company also introduced gelatin chloride printing-out paper which it marketed under the name "Solio." Adding further to its line of papers, the Eastman Kodak Company began production of "platino" paper, which was a mat silver bromide paper, a gelatin emulsion with starch added. These mat papers soon became quite popular (in contrast to the glossy papers).[45]

The middle 1890's witnessed a fierce battle for the paper market between the Kodak company and the American Aristotype Company of Jamestown, New York. The American Aristotype Company had been established in 1889 by two business men, Porter Sheldon and Charles S. Abbott. The firm produced both gelatin and collodion printing-out papers, which found a wide appeal among American photographers. A running advertising battle, known as the "Solio War," engaged the two leading producers of printing-out paper. Both firms continued to produce substantial quantities

45. Ackerman, pp. 94 and 103. The "Solio" trade name was seen in the various advertising pages of publications such as Anthony's Photographic Bulletin. See also Mees, "Leo Hendrik Baekeland and Photographic Printing Papers," Chemistry and Industry, XXXIII (1955), 1136-1137.

of paper, with Kodak coating in excess of one hundred miles of paper per week during the busy season of 1898.[46]

Other paper producers also appeared on the American scene at this time. Scovill Manufacturing Company (later, the Scovill and Adams Company) began production of bromide developing-out paper before 1887. Smaller firms began to appear in the larger metropolitan centers. While there were only two producers in the United States in 1880, a decade later this number had risen to nine. At the time of the introduction of the Kodak camera in the late 1880's and the subsequent rapid growth of amateur photography, the number of paper producers also began to increase, reaching a peak in 1897 with about twenty photographic paper manufacturers in the United States. This period saw, in addition to a rapid increase in demand for photographic materials, the introduction of some new types of paper.[47]

One of the most important new paper producers was Leo Hendrik Baekeland (1863-1944), who introduced Velox paper. Baekeland was born in Ghent, Belgium, and, after taking evening classes in chemistry and physics at the Ghent Municipal Technical School in addition to his regular high school courses, he entered the University of Ghent as a scholarship student in 1880. In four years he obtained

46. John P. Downs (ed.), History of Chautaugua County..., Vol. II, pp. 57 and 72; Ackerman, pp. 116-117 and 137.

47. American Annal of Photography, 1887, xli; Table 9.

both bachelor of science and doctor of science degrees (the latter maxima cum laude) in natural science. He specialized in chemistry and studied under Professor Theodore Swarts, the chief assistant and successor to Kekulé at Ghent. Baekeland received an appointment as Assistant Professor of Chemistry at the University of Ghent and in 1889 was promoted to associate professor. In that year he visited, on a traveling fellowship, a number of English and Scottish universities. He continued his travels to the United States, where he became acquainted with Charles F. Chandler, Professor of Chemistry at Columbia University, a chemical consultant to the Anthony company, and editor of the Photographic Bulletin. Baekeland was impressed to find in the United States, in contrast to conditions in Great Britain, interest and cpportunities in applied and industrial chemistry. Chandler persuaded Baekeland to remain in the United States. At a New York Camera Club meeting Baekeland met Richard A. Anthony of the Anthony company, who offered him a high salary to work for the photographic firm as a chemist.[48]

48. Charles F. Kettering, "Biographical Memoir of Leo Hendrik Baekeland, (1863-1944)," American Academy of Sciences, XXIV, 281-302; note that Kettering deviates from others on the date of Baekeland's employ with Anthony and his meeting of Professor Chandler and Richard Anthony; Leo H. Baekeland, "Dreams and Realities," Journal of Chemical Education, IX (1932), 1000-1009; H. V. Potter, "Leo Hendrik Baekeland...," Chemistry and Industry, XXIII (1945), 242-246 and 251-253; William Haynes, "Leo Baekeland," in Eduard Farber, ed., Great Chemists (New York, 1961), pp. 1183-1190; J. Gillis, Leo Hendrik Baekeland, Verzamelde Oorspronkeljjke Documenten

Anthony's offer actually brought Baekeland back into the field of photographic chemistry. In the early 1880's Baekeland had taken an interest in photochemistry, and in 1887 he had operated in Ghent a factory producing photographic plates. He had patented a self-developing plate and had received encouragement to continue his efforts from Belgium's leading photographic chemist and manufacturer of dry plates, D. Désiré van Monckhoven. Therefore, Baekeland was not entering upon a field foreign to his experience or interest. He remained in the employ of the Anthony company for over a year and then resigned to become an independent consulting and research chemist. In 1893 he carried out a number of experiments on gelatin chloride papers and discovered improved qualities due to his modifications of the standard process. In the same year in conjunction with an associate, Leonard Jacobi, Baekeland founded the Nepera Chemical Company in Yonkers, New York. Baekeland and Jacobi began small-scale production of photographic chemicals and paper, including Baekeland's new gelatin silver chloride paper, Velox. At first the public did not respond to the new paper, and the depression of 1893 did not ease the financial difficulties of the new company. Gradually, however, amateur interest in Velox grew. By the late 1890's the Velox paper was very

(Brussels, 1965); Goodwin vs Eastman, I, 426; a letter under the name of Leo H. Baekeland in Photog. J., LXX (1930), 490-492; C. E. K. Mees, "Leo Hendrik Baekeland and Photographic Printing Papers," Chemistry and Industry, XXXIII (1955), 1134-1138.

popular, and the company was on the road to success.[49]

Velox paper succeeded in gaining favor among photographers at this time because it possessed the advantages of both the developing-out and the printing-out papers. It was the first of the class known as "gaslight" papers. The name was given because the paper could be handled in subdued artificial light, an advantage over the more sensitive bromide papers. Yet it could be exposed by being placed at close range to artificial light, an advantage over printing-out papers. Velox was a developing-out paper and therefore possessed the advantages of that general class of paper.

In the manufacture of Velox paper, Baekeland brought two manufacturing innovations to paper production. First, he introduced the use of air conditioning in order to control both temperature and humidity conditions, important in the control of quality of the gelatin emulsion. Second, he installed silver chains on coating machines. These chains, by trailing over the continuous flow of paper, removed the static charge which built up on the paper, especially during the dry periods of the winter. Baekeland once remarked "in photographic paper factories hygrometers and electroscopes should be consulted as often as the thermometer."[50]

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49. *Ibid.*

50. Quotation from a 1903 paper delivered by Baekeland, from Kettering, pp. 281-302.

The increasing number of United States producers of photographic paper[51] and the competition of the American Aristotype Company and the Nepera Chemical Company stimulated Eastman to search for a method of rationalizing the photographic paper business. Following the idea used earlier by Vereinigten and Dresdener, Eastman conceived of controlling the production of photographic printing paper by controlling the production of the special raw paper. In London in 1898 George Eastman and Charles S. Abbott, President of General Aristotype Company, met with the officials of Steinbach & Company in Malmedy, Prussia, and Blanchet frères & Kleber in Rives, France, and consummated a general agreement. Under the terms of this agreement, these two leading raw paper producers joined in a common merchandising association, The General Paper Company of Brussels. The association set the quantity of production, the distribution of output, and the price of paper for Steinbach and Blanchet. The photographic paper companies which had purchased raw paper from these firms prior to 1897 continued to obtain a limited supply of raw paper but at substantially higher prices than before. However, no new photographic paper producers were to be sold raw paper. In addition, no photographic paper producers in the United States besides those interests represented by Eastman and Abbott

51. In 1890 there were nine photographic paper producers in the United States, and this figure rose to about twenty in 1897. See Table 9.

TABLE 9
NUMBER OF AMERICAN PHOTOGRAPHIC PAPER MANUFACTURERS, 1879 TO 1904[a]

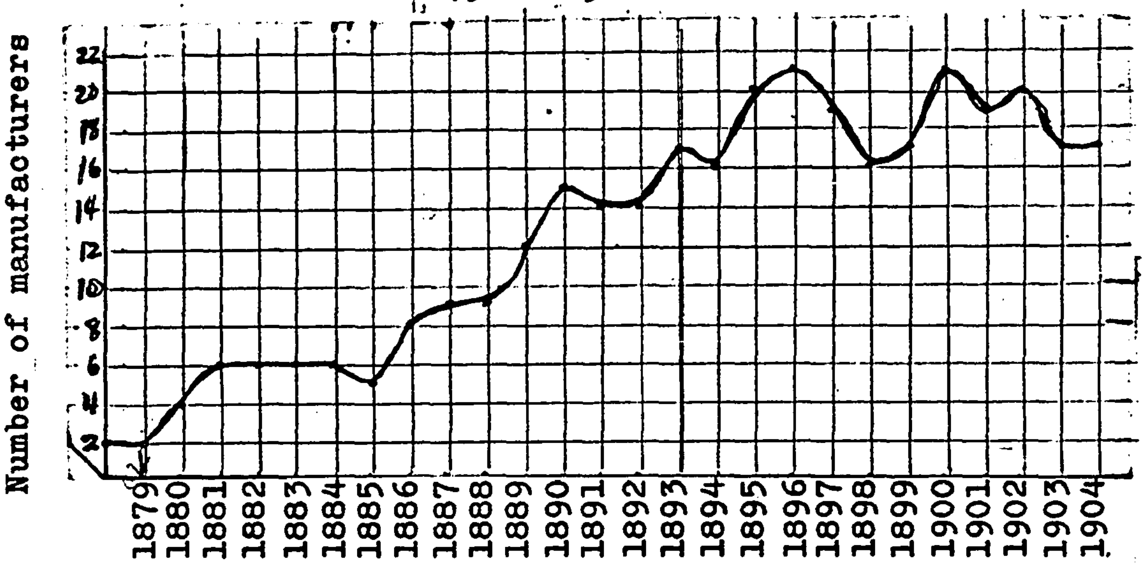
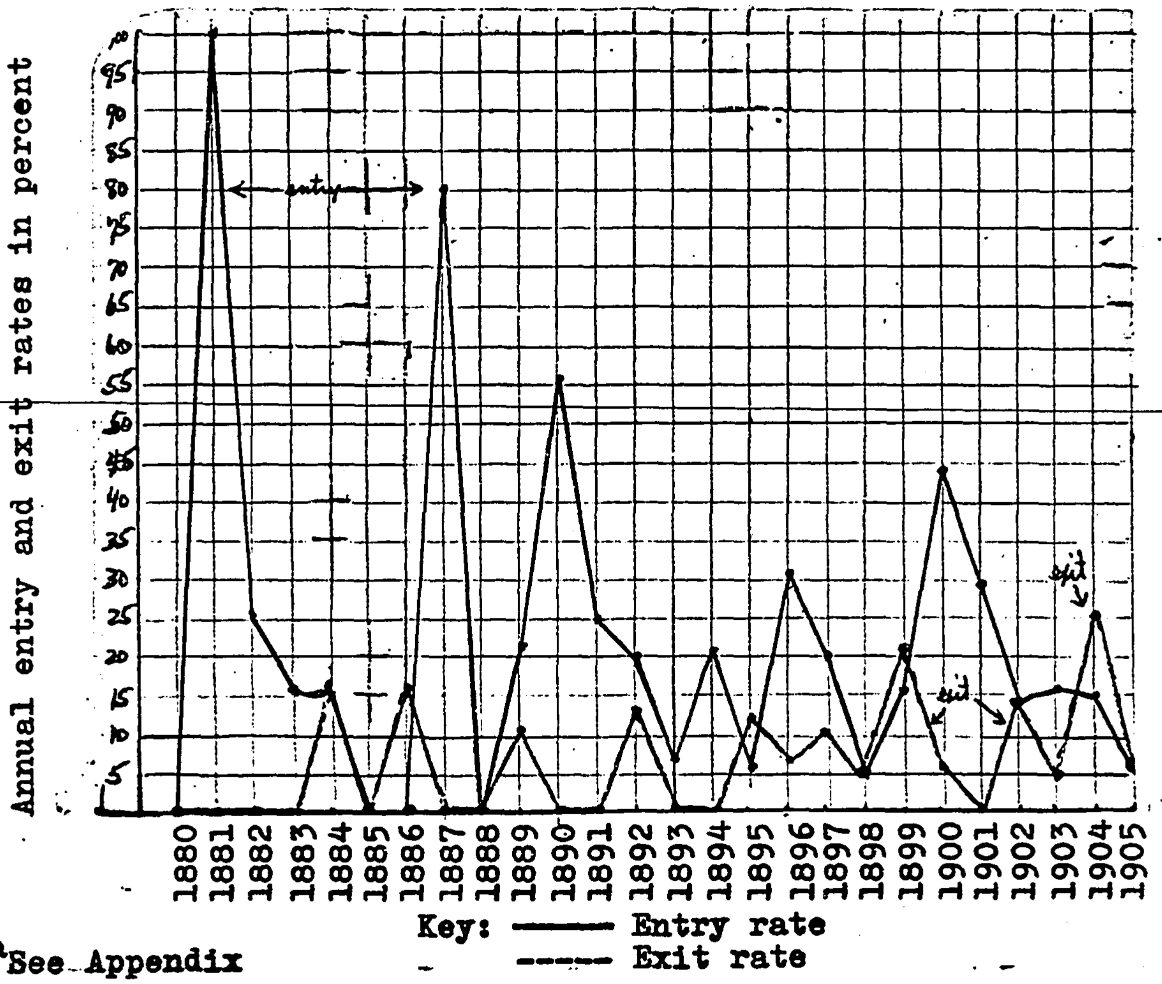


TABLE 10
ANNUAL ENTRY AND EXIT RATES FOR AMERICAN PAPER MANUFACTURERS, 1879 TO 1904[a]

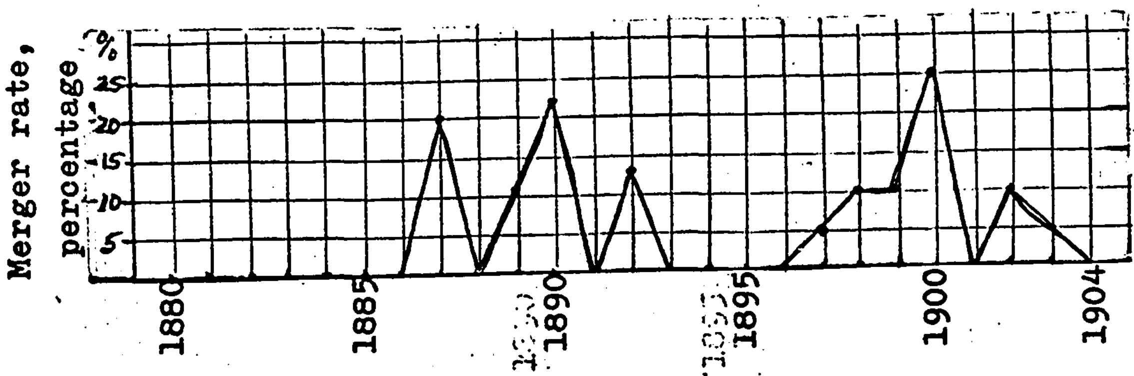


[a]See Appendix

TABLE 11

ANNUAL MERGER RATE FOR

AMERICAN PAPER MANUFACTURERS, 1879 TO 1904[a]



[a]See Appendix

were to obtain raw paper from the association.[52] The agreement covered a period of nine years.

The impact of this association was felt in both Europe and the United States. The older photographic paper manufacturers could not expand their output, and because of the advanced price of raw paper, they were hard pressed to compete with American photographic paper. The largest producers prior to the rise of the American industry, of course, were located in Germany. In order to further deter competition from this source, the Eastman interests set the price of raw paper higher for German producers than for those in England, France, and North America. In regard to the American market, General Paper Company agreed to pay a proportionate rebate on all raw paper purchased from it, manufactured into printing-out paper, and sold by the companies represented by Eastman and Abbott at reduced prices for the purpose of driving out competition. The effect of this agreement brought in the United States an increase in the price of most papers with the exception of those produced by the American Aristotype Company and Eastman Kodak Company. Also, the Eastman interests raised wholesale prices on their products to those dealers who did not agree to handle exclusively Eastman or American Aristotype papers.[53]

52. Federal Reporter, CCXXVI, p. 71; Ackerman, p. 167; Kuhn, pp. 63-64.

53. Federal Reporter, CCXXVI, pp. 71-73; Kühn, p. 64.

During the period of this move to control the production of photographic paper, Eastman Kodak Company began acquiring competing firms. In 1894 Eastman purchased Western Collodion Paper Company. In 1898 seven smaller firms were also acquired. In 1899, after the effect of the new paper agreement had begun to be felt, Eastman purchased from Baekeland on very generous terms the Nepera Chemical Company and the formula for Velox paper. At the same time, however, the owners, including Baekeland, were compelled to sign contracts wherein they agreed to leave the field of manufacture of photographic apparatus and materials for periods of from ten to twenty years. In the case of Baekeland, Eastman endeavored to add this important chemist to the scientific staff at Rochester, but, failing this, he obtained his agreement to remove himself from the field for twenty years. The combination of $750,000 for his Velox paper company and the agreement to leave photographic research and manufacture caused him to turn his attention to other chemical matters and led to the ultimate realization of his production of plastics.[54]

54. Haynes in "Leo Baekeland...," p. 1186, claims that Eastman offered $1 million to Baekeland, but C. E. K. Mees in "Leo Hendrik Baekeland...," p. 1136, indicates that Nepera Chemical Company sold for $750,000. The difference in figures may reflect differences in conditions wanted by Eastman and agreed to by Baekeland. See also: H. V. Potter, "Leo Baekeland...," p. 243; Federal Reporter, CCXXVI, p. 71.

Eastman consummated the rationalization of photographic paper production in 1899 with the formation of the General Aristotype Company, a merger of the paper producing divisions of Eastman Kodak Company, American Aristotype Company, Nepera Chemical Company, New Jersey Aristotype Company, Photo Materials Company, and Kirkland's Lithium Paper Company. The company was capitalized at five million dollars. In essence, the merger involved admitting the officers of American Aristotype Company into leadership of the Eastman Kodak Company and consolidation of management under the direction of Kodak. The ultimate consolidation came with the formation of the Eastman Kodak Company of New Jersey in 1901, which then acquired the General Aristotype Company. Actual production of paper remained, however, split between Rochester and Jamestown, New York.[55]

In response to the moves of Eastman and Abbott, several American companies struggled to survive. The two old American photographic supply companies, Anthony and Scovill, merged their operations and formed late in 1901 the Anthony and Scovill Company at a capitalization of $2½ million. Included in this combination were two smaller paper producers, the Columbian Photo Paper Company of Westfield, Massachusetts, and the Monarch Paper Company of Binghampton.[56] The efforts of Anthony and Scovill were

55. Ibid., CCXXVI, pp. 71-72; Ackerman, pp. 167-168 and 178-179.

56. Anthony's Photo Bulletin, XXXII (1902), p.2.

defensive and did not pose a threat to the Eastman combine. It remained for firms which came later to introduce new papers and techniques of production and, thereby, to challenge, though only feebly, the Kodak company.

At the turn of the century, then, Eastman had virtual world control of photographic printing paper. In the United States the General Aristotype Company produced 95% of the total output for 1901.[57] American producers, utilizing methods used earlier by the Dresden paper producers, wrested control of photographic paper production from Germany and gained for themselves a control at least as strict.

The growth of the photographic paper industry in the United States was aided by a close relationship between scientists and businessmen, though certainly not to the same degree as that in Germany in the 1860's. The work of Eastman and Walker in introducing bromide papers in the United States represented that of specialized and well-read technicians and amateurs. Professor Chandler of Columbia acted as a chemical consultant to the Anthony company and aided in bringing the talents of Leo Baekeland to the photographic industry of the United States. Without question, Baekeland represents both an important figure in the history of photographic papers and an important scientist with a practical and

57. Federal Reporter, CCXXVI, p. 74. See also Table 9 which indicates a drop in the number of photo paper producers from 1897 to 1900, a reflection of the merger movement. See Table 11 for merger rate in this period for paper manufacturers.

business orientation. By the 1890's Eastman was employing professional chemists for both research and practical work in the Rochester plant. Thus it appears that a combination of technically inclined businessmen seizing upon the important aspects of the chemistry, methods of production, source of supplies, and methods of distribution and assisted by a few trained chemists grasped control of production of this vital photographic material.

In conclusion, there were two stages in the development of the photographic paper industry during the nineteenth century. The first stage covered the period from the 1860's to the late 1880's, during which the German producers became dominant. In the early 1860's when the wet collodion process became popular, albumen paper came into widespread use. Producers such as Sanford and Spencer in England, Anthony in the United States, and Trapp, Liesegang, Kurz, and Schering in Germany soon became the major suppliers of this albumen paper; however, in the 1870's the German producers, by combining their production facilities and by acquiring control of the special raw paper supply in Rives and Malmedy, grew to a position of dominance in the world market. Many of these successful German firms had been established by academically trained chemists, while most of the founders of paper companies in the United States and England had not been so well trained in science. Although competition among German producers, especially in Dresden, did occur in the 1870's and 1880's,

the German photographic paper industry as a whole retained its position of leadership. The second stage began about 1890 but had grown out of earlier developments. During the 1870's English amateurs had introduced gelatin emulsions and soon employed them in the production of paper. Difficulties in handling and processing these new papers had retarded their rapid adoption. While it had taken only about six years from the time of introduction of gelatin emulsion until gelatin dry plates were accepted and produced on a commercial scale, it took from fifteen to twenty years before gelatin papers became popular. During this incubation period a revolution was underway in negative production, and as a result of the change to gelatin dry plates and then to gelatin coated celluloid film, the scale of production changed dramatically. In England, France, and the United States some dry plate producers gradually moved into production of gelatin papers. By the last decade of the century four major producers of the new photographic paper, Lumière, Eastman, American Aristotype, and Nepera, had emerged. Three of these four companies had very close ties with practical and research chemistry. Meanwhile, the established German producers were reluctant to move their production into gelatin papers and, therefore, lost their original position of leadership in paper production. These German companies as a result of their growth and increasing emphasis on business operations were no longer

controlled by academically trained scientists, and they appeared to be less adaptable than their new competitors to the changing technology. Furthermore, the retardation in the development of the German dry plate industry lessened the opportunity for new paper producers to emerge. It was the fresh spirit of the new enterprises in France and the United States -- those dry plate companies moving into paper production and those companies which started by producing the new photographic paper -- which initiated the new technology and exploited it.

At the turn of the century, the major American photographic paper companies merged under the leadership of Eastman. By acquiring control of the special paper production facilities at Rives and Malmedy, this new combine gained a dominant position in both the American and European markets. Once again the production of photographic papers was in the hands of one large company, and the monopoly position was maintained through control of the raw paper supply; the only basic differences between the structure of the industry in the 1870's and the structure in 1900 were that the scale of production was immensely larger at the turn of the century and the geographical center had moved from Dresden to Rochester.

The position of leadership in both stages seems to have been held initially by those companies with close ties with science; however, maintenance of the position rested upon control of the raw paper supply. The shift

from Dresden to Rochester came at the time of striking technological innovation and subsequent rapid changes in the scale of operations. Vigorous new firms using the techniques of the older German companies wrested control from them and maintained that control by keeping alert to further technological changes in the field.

Chapter VIII

CAMERA PRODUCTION

The camera and photo-optical industry changed character very substantially during the nineteenth century. The introduction of gelatin emulsions initiated this change. From the time of the introduction of photography until about 1880, craftsmen working by hand in small shops had made most cameras and lenses. However, with the introduction of gelatin dry plates, small hand cameras with inexpensive lenses became adequate for photographic purposes. The use of hand cameras, dry plates, and later roll film did much to simplify photography and, thereby, to broaden its appeal to amateurs. As a result, the demand for cameras and lenses increased very markedly. Many camera producers expanded their workshops into factories and introduced machinery to mass-produce amateur cameras. This expansion, of course, changed camera production from a craft to a booming industry. Yet not all producers carried out such an expansion. Some, especially in Germany, continued to produce high quality optical systems and cameras in their smaller workshops, appealing primarily to sophisticated amateurs or professional photographers. These producers, however, came to produce only a very small fraction of total output either in dollar value of gross sales or total number of cameras. This highly significant change

in the character of production grew out of the impact of two major advances in chemical technology, the development of gelatin emulsions and celluloid film, but exhibits to only a limited degree the direct influence of science.

CAMERA PRODUCTION, 1839-1880

For many years prior to 1839 Chevalier, the Parisian optician, built camera obscuras. Both Niepce and Daguerre obtained their camera needs from this capable lensmaker and craftsman. When Daguerre made public the details of his process, he granted Alphonse Giroux of Paris an exclusive license for the production of daguerreotype equipment.[1] Giroux, in turn, subcontracted with Chevalier and Lerebours for the production of the lenses for the Giroux cameras. This exclusive contract gave these French producers an initial lead in the production of daguerreotype equipment, and France became the world center of photographic equipment production during the 1840's.

The early daguerreotype equipment included a camera and other accessories. The camera consisted of two wooden boxes sliding into each other. Cabinet makers constructed such cameras in their small shops, though some photographers made their own and purchased the appropriate lenses. The daguerreotype kit came with a box for carrying silver-copper plates, a box for iodizing the silver-

1. This license is reproduced in full in the Appendix of Helmut Gernsheim, L. M. J. Daguerre (New York, 1959).

copper plates, and a mercury vapor box for developing the exposed plates. In addition to these bulky items, buffers and powders for polishing and bottles of the requisite chemicals completed the kit. The complete Giroux outfit weighed in excess of one hundred pounds. It is clear from the description of the daguerreotype kit that the major emphasis of production fell on the box making.[2]

However, Giroux possessed an exclusive hold on camera production in Paris for only a short time. Baron Pierre-Armand Seguier (1803-1876) soon assembled a traveling outfit which weighed only a third as much as the Giroux kit. In 1841 Alexis Gaudin began making a small, short-focus camera with a cloth flap as shutter on the lens. Louis Jules Duboscq (1817-1886), an operator of an optical firm in Paris who was responsible for the introduction in 1870 of a widely used colorimeter, also produced cameras and projectors.[3] By 1847 at least two thousand

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2. Daguerre provided an excellent description of his equipment in the various editions of his manual published in 1839 in Paris: *Historique et description des procédés du daguerréotype et du diorama*; an English edition of the same year is reproduced in Beaumont Newhall's work, *On Photography: a Source Book of Photo History in Facsimile* (Watkins Glen, New York, 1956).

3. *Chemical News*, XXXI (1870), 21; see also F. Szabadvary, *Geschichte der Analytischen Chemie* (Braunschweig, 1966), p. 337.

cameras were sold in Paris annually.[4]

In the 1850's Duboscq continued his production of cameras, extending manufacture to stereoscopic cameras, as introduced by Sir David Brewster in 1850. In the 1860's Bertsch in Paris became one of the leading camera producers.[5] After the change from the daguerreotype to negative photography, France lost to England its leadership in camera making. Though many small shops successfully produced cameras and other photographic equipment, France did not again play a major role in photography until the Lumière Company of Lyon appeared in the 1880's.

In England, initial interest and activity in photography and camera production were more subdued than in France, perhaps due to the number of patent restrictions unique to Great Britain. Andrew Ross produced photographic lenses at an early date, and Richard Beard, a coal merchant in London, purchased the patent and produced a few of Wolcott's mirror cameras. Alexander Wolcott, an American, had produced a reflecting camera in which a mirror acted as a light gatherer, replacing the usual objective lens. By 1841 Beard had these cameras in production, but they never became very popular. Another early British camera

4. See the following: Erich Stenger, The History of Photography..., trans. E. Epstean (Easton, Penna., 1939), p. 17; Gernsheim, pp. 110 and 118; Joseph M. Eder, History of Photography, trans. E. Epstean (New York, 1945), pp. 90 and 382; Abbé Moigno, Répertoire d'Optique Moderne (Paris, 1847).

5. Stenger, p. 23.

maker, Thomas Davidson, began constructing cameras and lenses in Scotland in 1841. Therefore, a few camera producers did appear in England in the early days of photography, but England did not seriously compete with France until the 1850's.

New names of camera manufacturers began to appear in England following the decline of popularity of the daguerreotype process. During the 1850's many of these firms, like the shops in France, did not confine their production to photographic equipment but also made philosophical instruments and optical goods.[6] Some of these companies began making special types of cameras. For example, J. J. Griffin and Company produced complete traveling photographic outfits in 1852. At about the same time J. F. Dancer, a Manchester optician, began production of stereoscopic cameras; a few years later the London Stereoscopic Company also began manufacture of this type of camera. In the 1860's the three leading camera producers in England, in contrast to the ones mentioned earlier, had begun to specialize in photographic equipment.[7] By 1869 at least one English firm, Manchester

6. Such firms included T. and R. Willats of London and Horne and Thornthwaite of London.

7. The three firms were: (1) McLean, Melhuish and Company; (2) P. Meagher, T. Ottevill and Company; and (3) Murray and Heath. The latter became the representative for Steinheil products in England.

Photographic Apparatus Manufacturers, had started to produce parts of cameras by machine.[8]

Therefore, between 1850 and the early 1870's a number of photographic apparatus manufacturers were active in England. These companies provided inexpensive cameras for German and French as well as for English photographers. The market came from professionals and enthusiastic amateurs; therefore, the demand was low and production modest, consisting generally of hand-made equipment.

In the United States, enthusiasm for photography was very great from the time of its first announcement. The details of the process reached the United States in September of 1839,[9] and by late November, Giroux had a representative in New York to sell apparatus. The agent did not prove trustworthy, and therefore Giroux's operations floundered in the United States from the first.[10] One of the early American manufacturers was Alexander Wolcott (1804-1844), who produced a few of his reflecting cameras, but his interest turned more to studio

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8. Humphrey's Journal, VII (May, 1855), 10; Moritz von Rohr, Theorie und Geschichte des Photographischen Objektivs (Berlin, 1899), pp. 213 and 228; Helmut and Alison Gernsheim, History of Photography... (London, 1955), pp. 157, 194, and 195; Photographic Journal, XIV (November 9, 1869), iii (ed); John Werge, Evolution of Photography (London, 1890), p. 77.

9. See discussion of dating problem in Robert Taft, Photography and the American Scene (New York, 1964), pp. 13-14.

10. Gernsheim, Daguerre..., p. 134.

photography than to apparatus production. In 1842 Edward Anthony, a civil engineer who had graduated from Columbia College in 1838, began a photographic supply shop in New York City and soon engaged in manufacture of apparatus and supplies. The Anthony factory was the first plant in America devoted exclusively to the manufacture of photographic goods. In 1852 Edward's brother, Henry T. Anthony, joined in forming the E. and H. T. Anthony Company, which continued as one of the leading American photographic suppliers and manufacturers during the remainder of the century.[11]

In 1851 W. T. and William Lewis established a large apparatus factory at Daguerreville, near Newburgh, New York. A contemporary journal claimed that it was the "largest manufactory for Daguerreotype apparatus in the world..."[12] Messrs. Lewis manufactured cameras, camera stands, chemical boxes, and headrests. They ground their own lenses for their cameras. Though the firm began with great expectations, it entered the field at a time when the daguerreotype had reached its peak of popularity in the United States and was beginning to decline. In a short time

11. Chauncey M. Depew (ed.), 1795-1895, One Hundred Years of American Commerce... (New York, 1895), Vol. II, p. 652; William Foote Seward (ed.) Binghampton and Broome County, New York...(New York, 1924), Vol II; William Haynes, American Chemical Industry (New York, 1949), Vol. VI, p.176; Prominent Families of New York... (New York, 1897), p. 22; L. R. Hamersly, Who's Who in New York City and State (New York, 1905), p. 24.

12. Daguerreian Journal, III (1851), 21.

the company changed hands and after 1854 was not heard of again.[13]

C. C. Harrison, an optician, founded in New York prior to 1851 one of the largest and most important American camera companies, establishing a reputation for manufacture of both cameras and camera lenses. In the early 1860's Nelson Wright acquired the Harrison Camera Factory, but he sold the establishment to the American Optical Company in 1866. This firm, organized as a joint-stock company, operated the camera production facilities of the Harrison factory and the apparatus factory of John Stock and Company. C. B. Boyle, designer of the ratio lens, was appointed optical director of the firm. In the late 1860's the Scovill Manufacturing Company of Waterbury, Connecticut, which had initiated production of cameras in the late 1850's, purchased the entire works of the American Optical Company but continued to use the name.[14]

Other firms also entered upon camera production in the United States. The firm of Holmes, Booth, and Haydens, established in Waterbury, Connecticut, in 1853, soon abandoned production of daguerreotypes and introduced

13. Ibid., II (1851), 370; III (1851), 20; IV (1852), 11-12; Hump. J., IV (1852), 28; IV(1853), 287; V (1854), 302.

14. Dag. J., I (1851), 189; Hump. J., VI (1854), 249; XVII (1866), 287; XVIII (1866), 9; and Philadelphia Photographer, VI (1869), 153-154.

camera manufacturing, vying successfully with C. C. Harrison.[15] S. D. Humphrey, editor of an influencial New York photographic journal, commented that in the middle 1850's, "C. C. Harrison's & Holmes, Booth and Haydens' cameras are, with very few exceptions, the only ones used in this country."[16]

Holmes, Booth and Haydens went out of business in 1866, and Charles F. Usener, the manager of their camera works during their thirteen years of operation, joined the firm of Willard Manufacturing Company in New York City. This company had been organized as a supply shop in 1857 and in 1865 had turned to manufacturing. During the summer of 1866 the company began camera production with Usener acting as superintendent. The Willard Company continued to supply cameras for the American market for some years.[17] Hence from an early date the American producers of cameras tended to specialize in production of photographic goods.

In the German-speaking countries, as in England, camera manufacture became closely associated with optical shops. During the 1840's Vienna became the center of camera and photographic objective production

15. Joseph Anderson (ed.), The Town and City of Waterbury, Conn.... (New Haven, 1896), Vol II, p. 352, and Vol III, p. 1042; Dag. J., II(1851), 213.

16. Hump. J., VI (1854), 137 and 249; VII (1855), 71.

17. Ibid., XVII (1865), 94 and 223; XVII (1866), 287; XVIII (June 15, 1866), ad; and XX (1869), 365.

of the German-speaking areas, but the activity diminished after mid-century. Without question the most important manufacturer in Vienna in the 1840's was Voigtländer. Johann Christoph Voigtländer (1732-1797) had founded the company in 1756 as a shop for the construction of philosophical instruments such as quandrants, compasses, and microscopes. Johann's grandson, Peter Friedrich (1812-1878), who had obtained a scientific education at the Vienna Polytechnique and in 1837 had begun directing the activities of the company, assisted Petzval with his work, undertaking construction and commercial production of the portrait lens, and directed the firm's interest into photographic optics. In 1840 the company began production of cameras. As indicated earlier, the Voigtländer firm continued to play an important role in the production of photographic objectives throughout the remainder of the century; however, the production operations were moved from Vienna to Braunschweig in 1849. After 1860 the company produced many photographic lenses which had been designed by other establishments, for example Steinheil's aplanatic, Zeiss's anastigmatic, and Cooke's triplet. After the Voigtländer move to Braunschweig, other opticians in Vienna carried on limited production in small shops, frequently copying older designs such as those of Petzval.[18]

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18. These opticians included Eckling, Prokesch Waible, and Weingartshofer; see "Geschichte der photographischen Optik in Wien," Photographische Korrespondenz, LXIV (1927),

Another large and influential optical company which played a role in production of photographic objectives was that of Emil Busch in Rathenow, Prussia. The firm was later known as Rathenower Optische Industrie Anstalt. August Duncker, a clergyman, had founded the firm in 1800. In 1845 Emil Busch, a grandson of Duncker, acquired the firm and actively promoted the production of spectacles, microscopes, photographic objectives, and cameras. At about this time the company initiated production of lenses on the basis of mathematical design rather than on a trial-and-error basis, as was customary at the time. Busch then expanded production to include telescopes and field and opera glasses. Though the Busch company did not introduce any really outstanding photographic objectives, it did put on the market a number of modifications of lenses of competing firms and in some cases acquired production licenses from its competitors. For example, Busch marketed a modification of the Petzval portrait lens and later, in 1867, brought out a modification of Dallmeyer's triplet. Likewise, in 1876 Busch produced aplanatic lenses based on Steinheil's model. One objective designed by the Busch company did become fairly popular, the "Pantoskop," put on the market

57 . Information on the Voigtländers and their firm is from Ibid., XXXVII (1900), 257; J. C. Poggendorff, Biographisch-Literarisches Handwörterbuch zur Geschichte der exacten Wissenschaften (Leipzig und Berlin, 1863-1962), II,1226-1227; Hump. J., XVII (1865), 311-315; Popular Photography, XXXVIII (May, 1956), 144.

in 1865.[19]

However, despite the efforts of these other German companies, after 1865 the Steinheil firm of Munich became the leader in the design of photographic objectives and also produced a few high quality cameras. The collaboration of Karl and Adolph Steinheil with Ludwig Seidel, it will be recalled, brought the Steinheil firm into the forefront with their production of the aplanatic lens. The firm continued to utilize mathematical ray-tracing techniques in its lens design and as a result brought out new photographic lenses which gave the firm a fine reputation throughout the remainder of the century.

Other camera producers appeared among opticians in large German cities, but little attention came to them because of their small scale of production. In 1839 in Berlin small producers such as Theodor Dörffel and Louis Sachse appeared. One of the more important of these smaller firms was that founded by Carl Keller of Wetzlar. Ernst Leitz purchased this small optical shop in 1869 and during the latter part of the century produced high quality cameras. Later this workshop merged with others to form the large camera firm, Ica.[20]

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19. See Karl Albrecht, Die Geschichte der Emil Busch A.-G. Optische Industrie Rathenow ([n.p.], 1926); British Journal of Photography, XXXXVII (1900), 89-90; Rohr, Theorie..., pp. 319-320; Willy Kühn, Die photographische Industrie Deutschlands... (Schweidnitz, 1929), p. 30.

20. Pop. Photog. XXXVIII (May, 1956), 121.

In summary, during the first forty years of photography, production of cameras and lenses remained generally in the hands of craftsmen working in small shops. Separate specialized firms for the production of cameras appeared only in the United States from the 1840's and in England from the 1860's; elsewhere, small optical shops or "philosophical instrument" producers supplied the limited demands of the professional photographer. The emphasis was on quality, and in that regard German firms already had begun to acquire a fine reputation by the middle 1860's. Initially France led in the production of apparatus, but after the decline in popularity of the daguerreotype, England began to take the lead, producing good, relatively inexpensive equipment. In the United States the camera manufacturers produced principally for the domestic market but did not try to compete seriously with the high quality products imported from Germany and England. The role of science in this period was relatively ~~small, outside of the part played by those physicists~~ working in the leading German optical firms.

CAMERA PRODUCTION, 1880-1900

The introduction of gelatin emulsions in the 1870's changed the character of the market for photographic apparatus. The market potential, greatly expanded by the introduction of the amateur, made large-scale production of cameras practical. As a consequence, the cost of

equipment became less, further enhancing the attractiveness of photography to the amateur. The subsequent loss of quality in cameras was compensated for by the technical advantages of the gelatin emulsions. The impact of these changes was felt in two stages during the last two decades of the century. The first stage came during the 1880's. The number of camera producers and the scale of their operations grew in response to the increasing amateur interest in hand cameras and dry plate photography, but these developments, though representing a tremendous step in simplification of photography, broadened the amateur market to only a limited degree. Though the increase in demand was substantial compared to that of the wet collodion process, it was very limited compared to the latent interest in photography. The second stage came in the 1890's with the successful introduction of the Kodak, a roll film camera, and the broadening of commercial facilities for chemical development of film exposed by amateur photographers. During this second stage the character of photographic apparatus changed, and photography truly became a big business. Though the scale of production had begun to increase during the 1880's, manufacturing was still carried on in small shops; by the end of the century, the scale of production had increased so substantially that all but those producing the highest quality products carried out machine production in large factories. With the ascendency

of the amateur in the market, the United States became the world's leader in the production of cameras, specializing in the inexpensive roll-film Kodak.

In 1880 of the four countries, German, France, England, and the United States, the United States and France were in the most backward position in the production of photographic objectives and cameras. Yet, because the increased sensitivity of the gelatin emulsions made the light-gathering power of photographic lenses less important than with wet collodion plates and consequently brought a market potential that also was not as discriminating about optical quality, the United States did not suffer because of its more sluggish start. During the 1880's the number of camera producers gradually increased, doubling over the decade from 1880-1890.[21] At the same time, the average capital per establishment and the average value of product per establishment increased sharply, indicating that the volume of business and the size of producers increased.[22] The value of output in photographic apparatus during this same decade increased more than six-fold.[23] Two Boston firms came into prominence in the 1880's, the Boston Camera Company and the Blair Camera Company. Both produced hand cameras and a variety of folding and pocket cameras.[24]

21. Table 12.

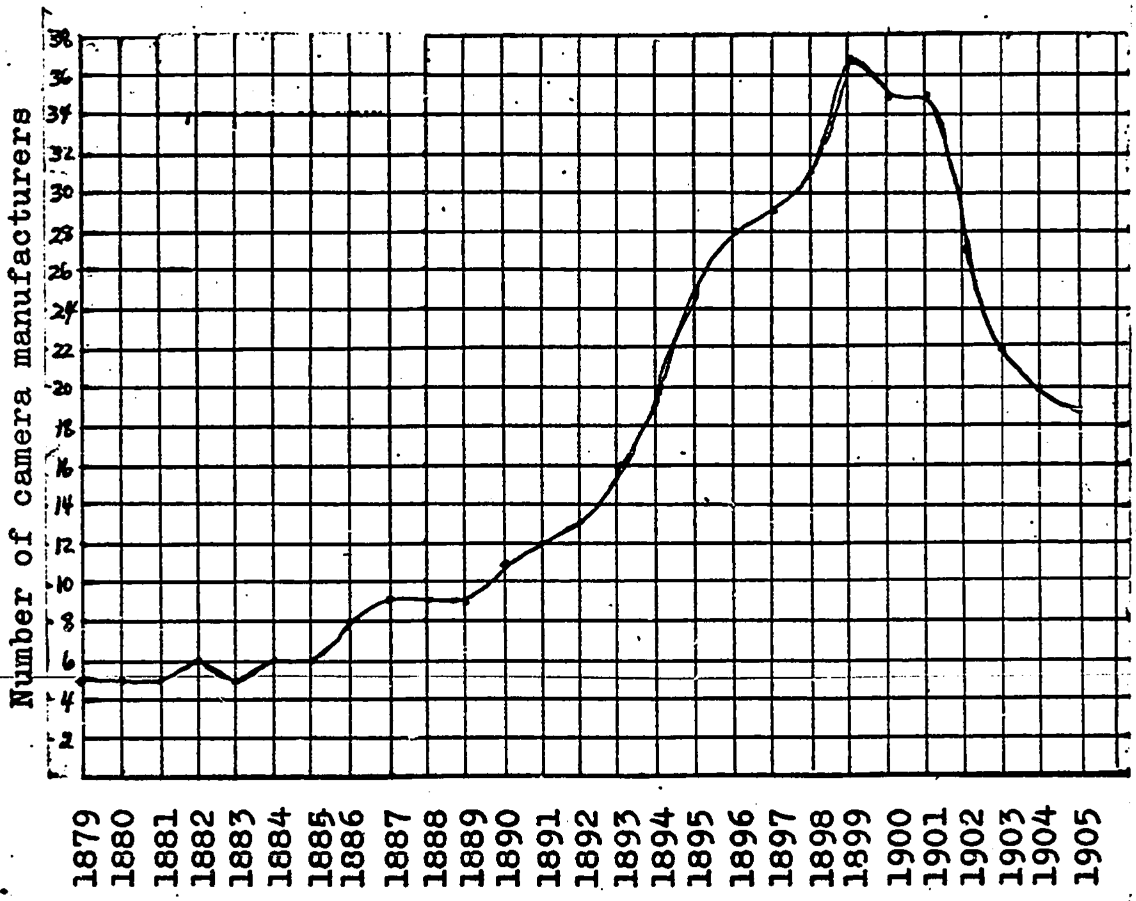
22. Tables 15 and 16.

23. Table 1.

24. Goodwin vs Eastman, III, 803-804; The Federal Reporter (St. Paul, 1916), CCXXVI, 68-70.

TABLE 12

NUMBER OF AMERICAN
CAMERA MANUFACTURERS, 1879 TO 1904[a]

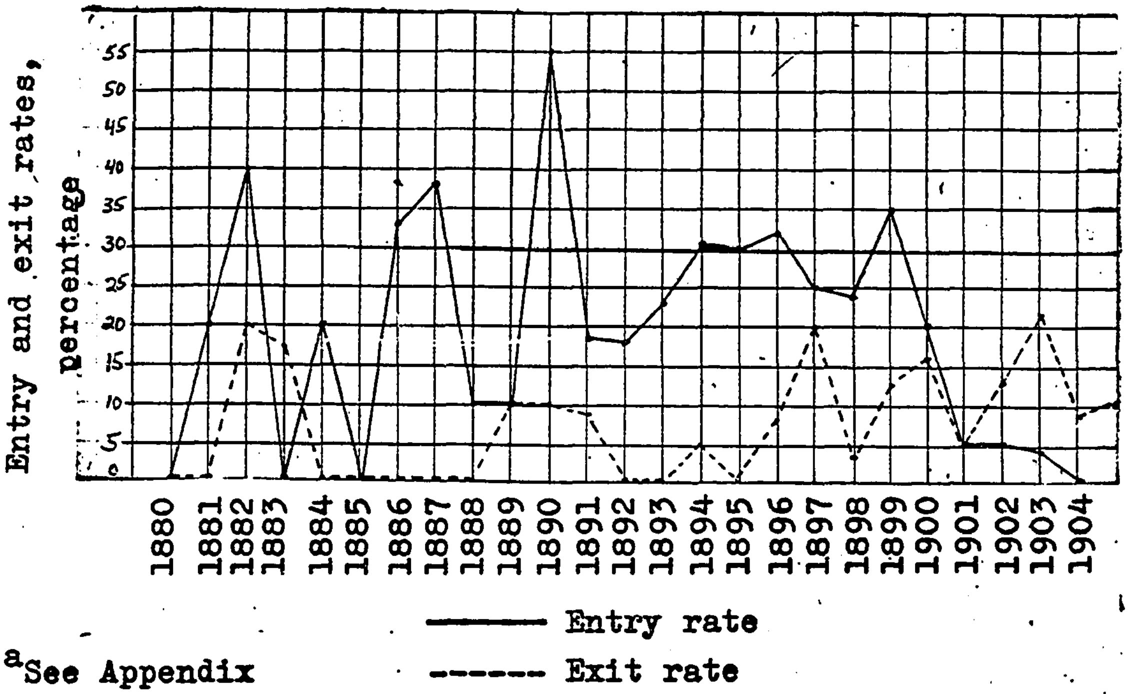


[a]See Appendix

TABLE 13

ANNUAL ENTRY AND EXIT RATES FOR

AMERICAN CAMERA MANUFACTURERS, 1879 TO 1904[a]

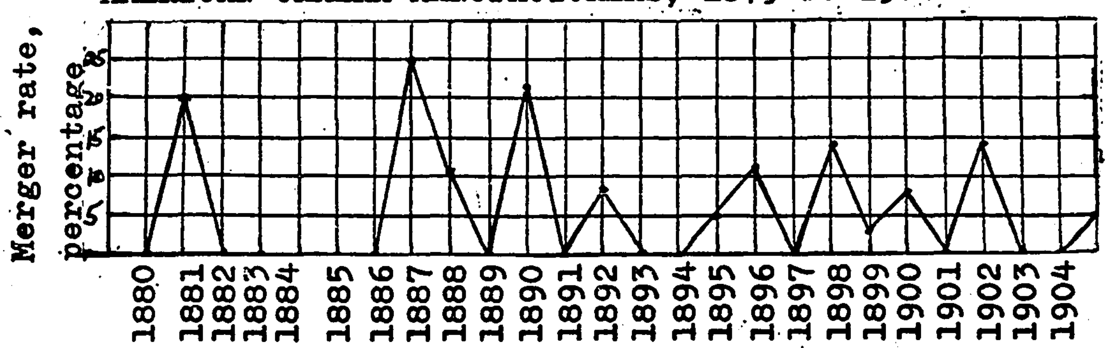


[a]See Appendix

TABLE 14

ANNUAL MERGER RATE FOR

AMERICAN CAMERA MANUFACTURERS, 1879 TO 1904[a]



[a]See Appendix

TABLE 15

AVERAGE CAPITAL PER ESTABLISHMENT FOR AMERICAN

PHOTOGRAPHIC APPARATUS MANUFACTURERS, 1879 TO 1904 [a]

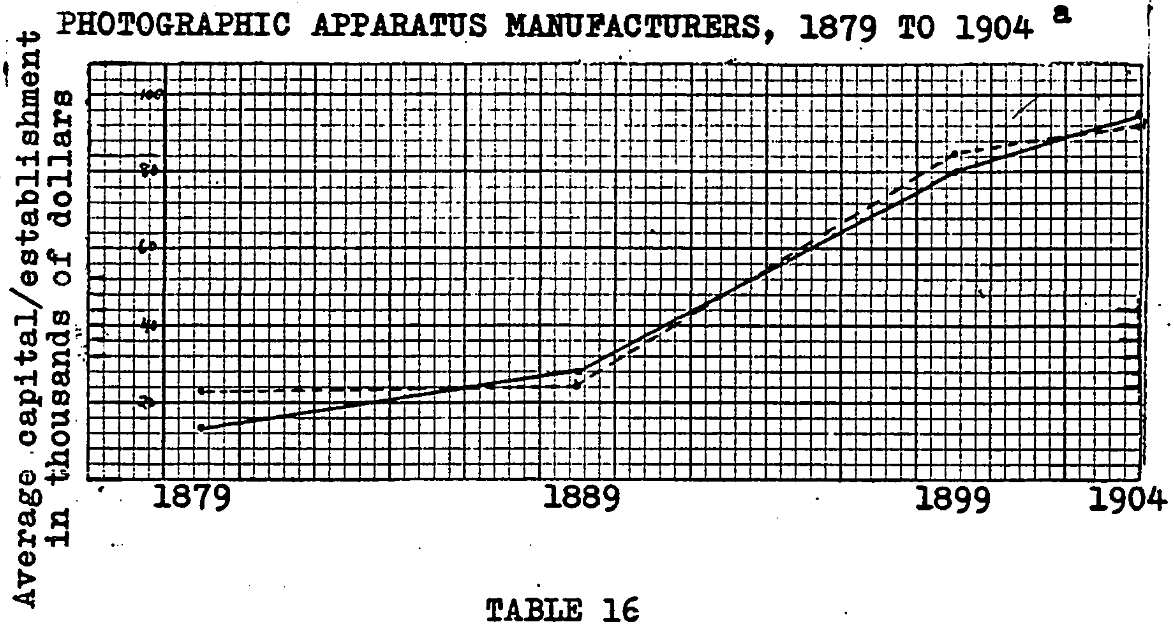
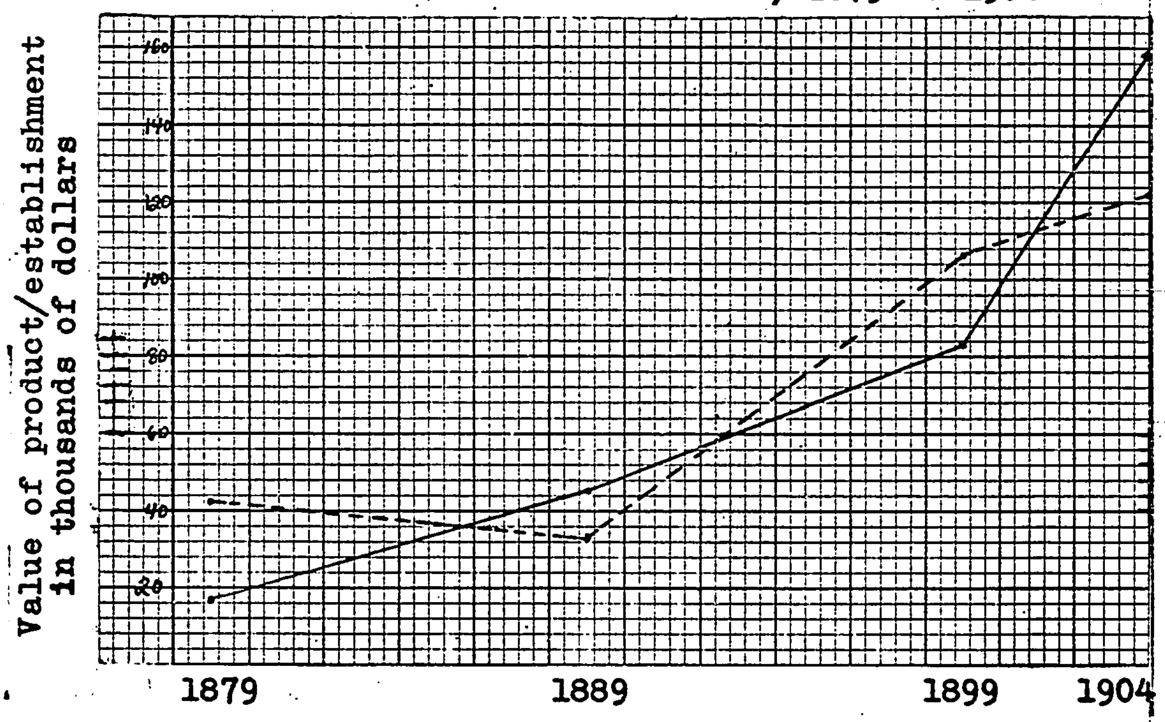


TABLE 16

VALUE OF PRODUCT PER ESTABLISHMENT FOR AMERICAN

PHOTOGRAPHIC APPARATUS MANUFACTURERS, 1879 TO 1904[a]

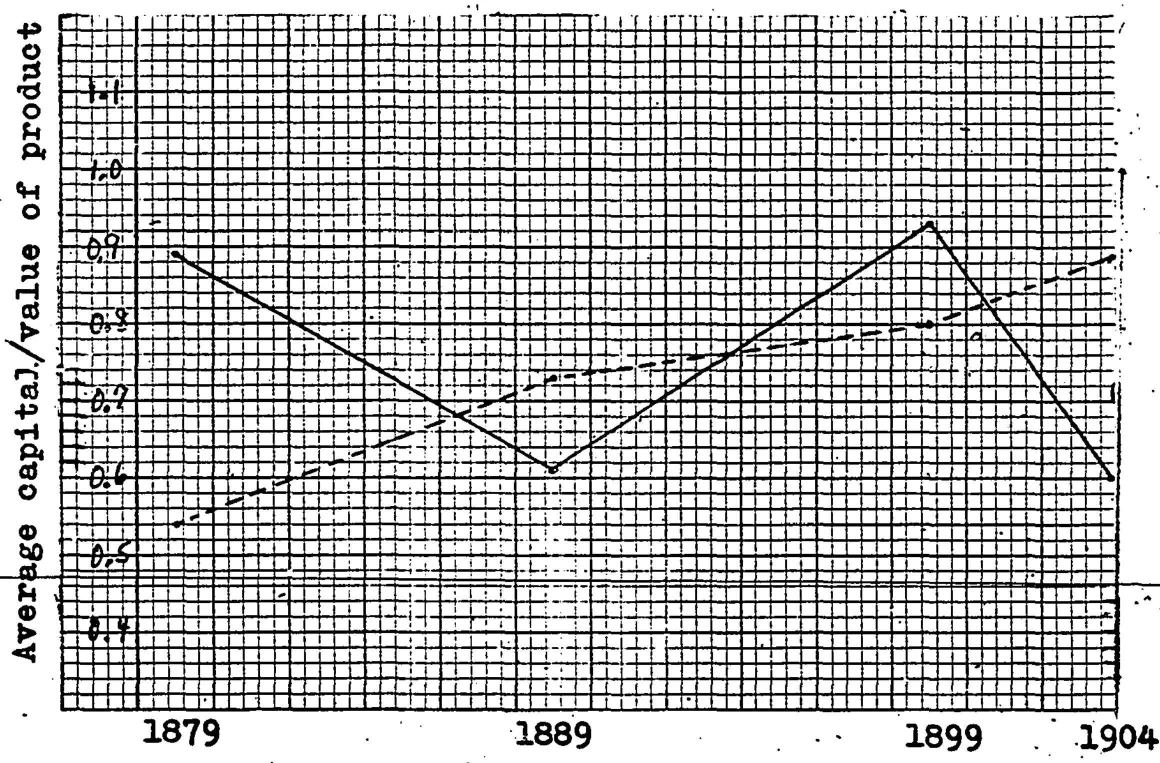


Key:
Photographic apparatus industry ————
All U. S. industry - - - - -

[a]See Appendix

TABLE 17

VALUE OF PRODUCT FOR
AMERICAN PHOTOGRAPHIC APPARATUS MANUFACTURERS,
1879 to 1904[a]



Key:
Photographic apparatus industry ————
All U. S. industry – – – – –

[a] See Appendix

The giant of the amateur camera industry, the Eastman Kodak Company, obtained its start during the 1880's. Entering upon production of photographic materials at the time of the introduction of gelatin dry plates, George Eastman made a commercial success of dry plate manufacturing, but he did not confine his attention to plates. In 1884 and 1885 Eastman and an associate, William H. Walker, patented gelatin coated paper, the roll holder for rolls of such paper or film, and machinery for making such paper. At first the roll holders were fitted into dry plate cameras, but the demand was small. These early cameras as well as most of the later Eastman cameras came equipped with inexpensive lenses and shutters produced by Eastman's neighbor, the Bausch and Lomb Optical Company of Rochester. In 1888 a complete roll film camera and outfit was marketed and called a "Kodak." In May of 1889 after the development of celluloid film, Eastman began a national advertising campaign, with full-page advertisements for the new Kodak camera appearing in at least a dozen of the nation's leading magazines. The response was excellent, and a large number of Kodaks were sold in the first few years of production.[25]

25. Goodwin vs Eastman, I, 318-319; Ackerman, George Eastman (London, 1930), pp. 45-54 and 80. Gernsheim (History..., p. 302) claims that 90,000 Kodaks were in use in 1891 while Ackerman (p. 111) claims that the 100,000th Kodak was produced in 1896. It seems unlikely that only 10,000 Kodaks were produced between 1891 and 1896 even though there was a depression in 1893. I suspect that the Gernsheim figure is a bit exaggerated.

The demand for Kodaks increased as Eastman began to introduce new types of cameras. In 1895 Eastman marketed the folding pocket Kodak, equipped to take six-and twelve-exposure rolls of film. Soon production was at the rate of 150 per day, while the European market alone demanded 2,000 per month. In a short time production sights were raised to 600 per day. In 1896 the least expensive Kodak cost $5, and twelve-exposure film cost $0.60 per roll. The cost reductions brought increasing demand for these inexpensive hand cameras. The Rochester plant, already the largest in the world, employed 900 persons in the camera department alone and operated on an eighteen-hour day. In late 1896 and 1897 the firm built a $200,000 addition to the Kodak Park camera works and employed an additional six hundred workers. In February of 1897 European dealers alone ordered 5000 Kodaks and 20,000 rolls of film. The Eastman company's first quarter sales showed a 71 per cent increase in European sales and an 85 per cent increase in domestic sales over the sales of the last quarter of 1896. In 1900 cost reduction culminated in the introduction of the Kodak Brownie Camera, which sold for one dollar. By the end of the century the Eastman company, in spite of thirteen domestic and many foreign competitors, was the largest and most dominant camera producer in the world.[26]

As a result of the emergence of the Eastman company

26. Ackerman, pp. 116, 120, 121, and 171; Photo-American XVIII (1907), p. 160.

as the leading camera producer, the structure of photographic apparatus manufacture in the United States underwent substantial change. The value of output in the decade 1889 to 1899 increased four-fold[27] at the same time that there was substantial cost reduction in cameras, especially in amateur cameras.[28] The number of camera producers in the United States also increased four-fold in the same decade, in spite of the economic depression of 1893.[29] The average capital per establishment rose more than three-fold, and the average value of product per establishment more than doubled.[30] These figures reflect the increasing size of firms and the extensive use of power machinery. At the same time, the average capital per value of product rose fifty per cent.[31] This rise, along with the sharp rise in the number of camera producers, may reflect that a large number of small producers were drawn into the field by the success of the Eastman company. Many of these firms, even though they entered with substantial financial backing, could not successfully compete with the Eastman company. Figures after the turn of the century show a substantial drop in both the number of camera

27. Table 1.

28. The original Kodak cost $25; in 1896 the cost was down to $5; and in 1900 the cost of the Kodak Brownie Camera was $1.

29. Table 12.

30. Table 15 and Table 16.

31. Table 17.

manufacturers and the average capital per value of output ratio.[32] Entry into camera manufacturing was relatively easy, but Eastman's comprehensive holdings of camera patents limited the areas of production. This was true not only in the United States but in Europe as well.

From the very beginning of his business career, George Eastman sought to secure both foreign and domestic patents for his photographic equipment and production machinery.[33] Eastman brought William Walker into the firm in 1884 in order to secure patents which Walker held on roll holders for film cameras. In 1886 Eastman began purchasing patents on various desirable features for cameras, for example, those of David H. Houston.[34] In the middle and late 1890's, Eastman purchased at substantial sums three major camera producers, the Boston Camera Company (1895), the American Camera Company (1898), and the Blair Camera Company (1899), in order to secure patents which would protect and further enhance the Kodak

32. Tables 12 and 17.

33. For example, Eastman obtained a German patent on a glass coating machine on January 27, 1880. DRP #11,832, Henri Silbermann, Fortschritte auf dem Gebiete der Photo- und Chemigraphischen Reproductionsverfahren, 1877-1906... (Leipzig, 1907), Vol I, p. 49. Among other German patents which he obtained were: DRP 34,029; 54,214; 59,267; and 69,231. Ibid., Vol I, pp. 49, 71, 53-57; and 70.

34. Ackerman, pp. 57-58; but see also the claims of a Houston relative in a bitter attack on Eastman: Mina Fisher Hammer, History of the Kodak... (New York, 1940).

camera.[35] As a result of Eastman's patent holdings and because of the substantial capital required for machinery to mass-produce the popular roll-film cameras, it was nearly impossible for any other manufacturer at this time to produce them. Therefore, new entrants to the camera production field were confined to developing and producing dry plate cameras, which had only a small and diminishing portion of the total market. Furthermore, American producers of dry plate cameras, in spite of high duties on foreign lenses and cameras imposed by the McKinley Tariff,[36] also had to compete with German and English cameras, the producers of which already had the advantage of previous experience in production of quality optical systems and cameras. A few companies, such as Bausch and Lomb, which supplied the Eastman company with its lenses, could draw on their long optical experience and produce high quality specialty cameras. Though they added little to new designs in lenses, they did acquire exclusive American rights to produce the Zeiss anastigmatic lens. Ernst Gundlach, an emigrant from Berlin, was another producer who, because of his previous optical experience, succeeded in acquiring a specialized clientel for his quality equipment; but, as the statistics indicate, by

35. The Federal Reporter, CCXXVI, 69.

36. House of Representatives, 61st Congress, 2nd Session, Tariff Acts Passed by the Congress of the United States, Document #671 (Washington, 1909), pp. 403, 471, 553, and 673.

the end of the century many firms, both large and small, had encountered difficulty and had gone out of business.

In the period from 1890 to 1910, when the competition became keen, just as in the photographic paper industry in the United States, there was considerable consolidation of firms. The Eastman company itself led the way in this movement, acquiring firms that held patents or markets of interest to it.[37]

The rapid growth and influence of the Eastman company affected the relative positions of the European producers, especially those in England. Prior to the introduction of gelatin emulsions, English producers had been the source of inexpensive cameras, but by the end of the century, Eastman had become the leading supplier of such cameras. Because of England's early advantage in dry plate production, a number of materials producers, such as Britannia and Wratten & Wainwright arose, but these firms did not turn their attention to cameras. During the 1880's several firms did enter and make some success. One of the largest was Thornton-Pickard Manufacturing Company, Ltd., near London. Founded in 1889 by J. E. Thornton and Edgar Pickard, the firm expanded rapidly, producing cameras, plate-holders, shutters, and lenses. During 1896 it was producing as many as 500 shutters per week.[38]

37. The Federal Reporter, CCXXVI, pp. 68-70 and p. 75.

38. Brit. J. Photog., XLVII (1900), 59-60; and Photographic News, XL (1896), 6-8.

The largest camera distributor in England was the Eastman company. The Eastman Dry Plate and Film Company started branch operations in England in 1885. In 1889, however, Eastman established a separate firm at Harrow, England, the Eastman Photographic Materials Company, Ltd., which took over not only the operations of the English plant but the business of branches in at least ten other countries. This English firm imported cameras from Rochester for distribution throughout Europe and Asia. Therefore, in spite of the Eastman Company being the largest operation in England in the photographic field, the English branch did not actually produce cameras.[39]

France possessed few important camera manufacturers during the last quarter of the century. In Paris there were two smaller producers, Bertsch, who had produced cameras since the early 1860's, and Thomas E. Enjalbert, who began manufacture in 1889.[40] France's largest photographic manufacturer, Lumière of Lyon, did not engage in production of cameras until he introduced a movie camera in 1895. He did not fully develop even this specialized type of equipment, confining his operations principally to chemically related products. The Eastman company also operated a plant at Nice, but this plant, like the one in England, merely acted as a distributor of Rochester-produced cameras. On the whole, France's position in

39. Ibid., XXXV (1891), 151; XXXVII (1893), 12.
40. Stenger, pp. 23-25.

photographic apparatus production had slipped substantially since mid-century, and there was no sign of recovery by the end of the century. This may well have been a reflection of the relative economic stagnation of France during the second half of the nineteenth century.[41]

German producers of cameras were also hit by the competition of Kodaks, but in many respects they competed more successfully than the English or French and, therefore, were better able to hold a place in the market for themselves. At the time of the introduction of gelatin emulsions, the Germans already had a reputation for excellence in optical design and cameras. Therefore, by maintaining high standards, a number of older firms held their positions, and several new companies successfully entered upon production and prospered.

Several optical firms previously mentioned successfully made the transfer from wet collodion photography to dry plate photography. Voigtländer in Braunschweig continued operations with emphasis on photographic

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41. Cameron argues that this economic stagnation which was reflected in relative weakness in the industrial sector of the economy was due to slow population growth, inappropriate raw material endowment, and failure to invest in domestic enterprise. See Rondo E. Cameron, "Economic Growth and Stagnation in France, 1815-1914," in Barry E. Supple, ed., _The Experience of Economic Growth, Case Studies in Economic History_ (New York, 1963), pp. 328-339. Landes argues, on the other hand, that the French businessman was fundamentally conservative and overly cautious. See David S. Landes, "French Entrepreneurship and Industrial Growth in the Nineteenth Century," _Ibid._, pp. 340-353.

objectives rather than cameras, utilizing developments of other optical firms such as Zeiss. Zeiss also acted as optical supplier to smaller camera producers. The Steinheil firm, under the direction of Dr. Rudolph Steinheil (1865-1930), developed new photographic objectives, utilizing the services of academically-trained scientists in their design, for example, Dr. Karl Strehl. The Rathenower Optische Industrie Anstalt (formerly Emil Busch) continued to produce cameras and lenses, expanding operations substantially over half a century. In 1845 it employed sventy men, while in 1900 it employed about seven thousand. Late in the century Busch sold his interest in the firm, and it became a joint-stock company.[42] Zeiss Optical Company in Jena started its photographic division in 1890 and, of course, had an initial success with the marketing of the anastigmatic lens. Rather than overburden its own production facilities, the company granted production licenses to firms in seven countries, including Bausch and Lomb Optical Company in Rochester, Ross and Company in London, and Voigtländer in Braunschweig.[43] With the resignation of Carl Zeiss's son Roderick from the firm in 1889, Abbe strengthened the scientific orientation of the management by appointing as joint directors of the firm, in addition to himself, Schott and Czapski.

Siegfried Czapski (1861-1907) had studied chemistry,

42. Brit. J. Photog., XLVII (1900), 89-90.
43. Rohr, p. 366.

physics, and mathematics at the University of Göttingen and Breslau under Helmholtz and Kirchhoff, obtaining his Ph.D. degree at Breslau in 1884. Shortly after graduation, he had come to Jena as an assistant to Abbe. In 1893 he received the appointment as co-director of Zeiss Optical Company and in 1902 succeeded Abbe as head of the Zeiss Foundation.[44]

Not all German camera manufacturers grew out of the optical industry. In fact, some camera firms such as Goerz and Ernemann started as cabinet workshops and eventually moved into optical production. One of the largest camera producers in Germany at the end of the century was that of C. P. Goerz in Berlin.

Carl Paul Goerz (1856-1930), after obtaining an education in the lower schools, became an apprentice at the optical plant of Emil Busch in Rathenow. In 1886 he established a shop for selling scientific instruments in Berlin and two years later began production of cameras. For a few years Goerz utilized the lenses of Dallmeyer and Steinheil, but by employing Emil von Hoegh, an optical theorist, to work on optical design of cmaera objectives, he was able to market Hoegh's double-anastigmatic lens in 1893. In 1890 Goerz had collaborated with the photographer Ottomar Anschütz to produce a new kind of camera, the Goerz-Anschütz focal-plane-shutter camera,

44. Brit. J. Photog., LIV (1907), 522-523; Friedrich Schomerus, Geschichte des Jenaer Zeisswerkes, 1846-1946, (Stuttgart, 1952).

which became very popular for rapid photography. By 1895 Goerz had produced 25,000 photographic lenses. As Goerz obtained commercial success in production of lenses, he extended manufacture to prismatic binoculars. In 1895 he established offices and plants in Paris and New York. Soon additional manufacturing plants were opened in London, Petersburg, and Pressburg. In 1897 Goerz introduced machine production. Some indication of the expansion of this firm is given by employment figures. In 1890 the firm employed twenty-five, in 1893 one hundred, in 1895 two hundred, and in 1900 one thousand. Such expansion continued until World War I. The success of this firm was due in part to its entry into optical research and the development of new and distinctive types of cameras.[45]

Another progressive, though smaller, camera company which also moved into optical products was the company of Heinrich Ernemann in Dresden. Ernemann had founded the company in 1889 when he employed six carpenters to make wooden cameras. Stimulated by the appearance of the first American hand cameras, by 1892 he had expanded into a factory and employed machinery to produce amateur cameras. Toward the end of the century Ernemann, in addition to producing his own camera lenses, took up design and manufacture of cinema cameras. In 1898 further expansion of

45. Kühn, pp. 24-25, 35, and 90; and Stenger, p. 145.

production and facilities came when the firm merged with the camera factory of Herbst and Firl in Görlitz.[46]

Herbst and Firl had founded their camera factory in 1889. At that time they had employed only one other person, a carpenter. In 1893 they had moved into a factory and had increased their help to more than twenty-five men because of the increase in demand for hand cameras. Soon they had expanded their work force to seventy men. In 1898 they merged their operations with those of Ernemann in Dresden. The success of this merger made Dresden the leading German center for production of amateur cameras, though the roll-film cameras which were not produced in Germany competed strongly with this firm.[47]

As in the United States, at the turn of the century some camera manufacturers in Germany began to combine their operations. In addition to the merger of Herbst and Firl and Ernemann, Emil Wünsche's company was founded in Reick near Dresden as a result of the merger of at least four smaller camera companies. A very large consolidation occurred in the first decade of the century with the merger of the photographic division of Zeiss and the firms of R. Hüttig und Sohn in Dresden, Emil Wünsche in Reick, and Dr. R. Krügener in Frankfurt a. M., into the Ica Company of Dresden.[48]

46. Kühn, pp. 19-21 and 91-92.
47. *Ibid.*, pp. 19 and 92.
48. *Ibid.*, pp. 116-118.

Thus, until the introduction of the dry plate, the number of firms and the extent of camera production were small. Most companies producing cameras prior to 1880 were also engaged in either general optical production or scientific instrument construction. The introduction of gelatin emulsions brought a revolution in demand for photographic apparatus, with the result that large-scale mass production became possible, as demonstrated by the Eastman and Goerz companies. The introduction of thin celluloid film, brought a further simplification of photography and an increase in popularity of photography among amateurs. As the result of laboratory experimentation, patent control, and agressive marketing, the Eastman company came to control a very large part of the world amateur market in film photography. Its successful exploitation of the Kodak grew out of its control of celluloid film. Yet there still remained room for smaller companies to market high-quality and specialty cameras. In this area, the German companies excelled. Some of these camera companies grew out of divisions in optical firms such as Zeiss, while others like Goerz and Ernemann entered the field at the time the amateur entered the market and thus found a sufficient demand for their products. In Germany many of the companies were closely linked to science from the beginning, especially those companies growing out of optical manufacture. The companies which seemed to succeed most quickly were the

ones with scientific personnel on their staff. These people probably aided in keeping the companies flexible and open to exploiting new ideas and features. In the case of the Eastman company, the personnel working directly with cameras were not scientifically trained; however, George Eastman had the idea of using film in cameras, and he succeeded in making it work with the assistance of Reichenbach, his research chemist. Unlike some of the older companies, established during or before the wet collodion period, the Eastman firm did not have heavy investments in equipment to produce older style cameras and, therefore, could move in new directions. Also of great importance in the success of the American firm was flexibility and openness to new ideas. In fact, Eastman sought to buy the patents on nearly all new ideas connected with cameras except those developed in Germany, a region rather removed from his direct attention. Eastman's commercial success in dry plate production provided the capital base for exploitation of new ideas in other areas.

The direct role of science and technology in the industrial development of camera production was more remote than in the photographic materials industry; yet the structure and potential of the camera industry were highly dependent upon the important technological advances in photographic materials and, in particular, upon the development of gelatin emulsions and thin celluloid film. These technical advances made it possible for Eastman to

build the Kodak and say to the amateur, "You press the button and we'll do the rest."

Chapter IX

CONCLUSION

After an examination of the development of the photographic industry in the nineteenth century, it is clear that the patterns of development of technology were strongly influenced by progress in science and that this technology, in turn, affected growth of the photographic industry. However, the patterns of influence and dependence changed as the result of changes in the interacting forces. Photographic technology in the middle of the century was strongly dependent upon chemical discoveries made during the previous half century. When, at the beginning of the nineteenth century, Davy and Wedgwood had utilized silver nitrate and silver chloride as sensitive salts and material which had been tanned as an accelerating medium, they had brought together discoveries from an earlier time. Their efforts to fix chemically camera obscura images had failed for want of a suitable solvent for their principal photosensitive material, silver chloride. During the next four decades the isolation of iodine by Davy and bromine by Balard and their immediate discoveries of the light sensitivity of their silver salts helped to lay the groundwork for the discovery and rapid development of photography. The separation of gallic acid and pyrogallol from tanning solutions by Braconnot provided a further base upon which photographic technology would

develop. Also, John Herschel's study of hyposulfurous compounds and their properties provided an important link in the initial advance of photographic technology.

In addition to providing the chemical base upon which the new technology was to grow, science also played an important role as midwife and nurse in giving birth to photography and in nurturing the infant during its early years. Daguerre obtained substantial encouragement and assistance from such leading Parisian scientists of his day as Arago, Biot, Humboldt, and Gay-Lussac. Biot and Arago especially fostered the work of Daguerre, making announcements to l'Académie des Sciences, composing papers on his process for entry in <u>Comptes rendus</u>, and securing for Daguerre a financial stipend. In England the Royal Society provided a forum for the exchange of ideas and the presentation and publication of papers such as those by Herschel, Talbot, and Claudet. This enthusiastic reception of photography and interest in its progress continued for about a decade and a half. During that time many leading scientists such as Biot, Arago, Herschel, Fizeau, Foucault, Regnault, Brewster, Draper, and Liebig turned attention to the chemistry of photography and sought to improve upon the practical process. The Royal Society and l'Académie des Sciences became forums for discussion of the problems of photography, and <u>The Philosophical Transactions</u>, <u>The Philosophical Magazine</u>, and <u>Comptes rendus</u>

published numerous articles on the subject. Less publicized activities such as those of Herschel, Talbot, and Biot in introducing sodium thiosulfate as a fixing agent for the daguerreotype process also contributed to advances in photographic technology.

During this period of close association between science and technology, discoveries made by trained investigators were rapidly incorporated into the art. Within a year of Arago's announcement that the process existed, sodium thiosulfate and silver bromide were introduced. In a short time gold toning became standard procedure. Pyrogallol was introduced as a developer by both Liebig and Regnault. Schönbein's discovery of nitrocellulose and the subsequent preparation of collodion strongly influenced photographic technology, with collodion photography soon replacing the daguerreotype process.

By the middle of the 1850's, however, the close relations between science and photography had begun to decline. At this time independent photographic societies began to emerge in England, France, and the United States, and publication of independent photographic journals began. Papers on photography became concentrated in the technical journals and seldom reached the scientific publications. Therefore, the photographer and the scientist parted company. After this organizational break, which occurred during the early 1850's, the influence of science and

scientists on photography diminished It is striking that the first twenty years of this period of relative decline in science-photography relations is also a stagnant time in terms of the introduction of new ideas. Gelatin emulsions were introduced in the early 1870's as a result of amateur efforts and owed little to the chemistry of that day. Once photography made contact with science again through industrial chemists such as Andresen, the Lumières, Seyewetz, Hurter, and Driffield during the last two decades of the century, numerous advances in technology, including a number of new organic developers, celluloid film, and extended color sensitivity of emulsions, were forthcoming.

During most of the century an unusually close relationship existed between the innovators in photographic optics and science. The initial quality of photographic objectives was due in large part to the significant advance in design and rapid increase in use of the microscope a decade prior to the introduction of the daguerreotype. Soon, further improvements in objectives came with scientific lens design such as that of Petzval and with trial-and-error methods used by philosophical instrument makers and opticians such as Ross and Chevalier. The Steinheils' success demonstrates that mathematical ray-tracing techniques had begun to provide the basis for improved designs for photographic objectives. In Germany, in particular, from an early

period the innovators in photographic optics tended to be academically trained scientists who also conducted their own businesses or were closely connected with established optical firms. This close dependence of photography on optical science is illustrated in the operations of leading German firms such as Steinheil, Busch, and Voigtländer During the last decade of the century the impact of the new Jena glass stimulated the work of physicists dealing with lens design. In Germany the development of the new glass, due to the encouragement of the Zeiss firm, led to the establishment of the photographic division of Zeiss, thereby bringing to bear upon photographic optics the talents of that firm's excellent scientific staff. Also during the last decade of the century, England turned increasingly to mathematical ray-tracing techniques with the work of Schroeder and Cooke being particularly significant. Thus, developments in photographic objectives became increasingly dependent upon science and scientific personnel as the century progressed.

While photographic technology rested upon developments in chemistry and optics, the pattern of growth and retardation of the industry depended heavily upon the pattern of development in technology. Technology affected the industry in at least three ways. First, it determined whether factory production of certain materials was possible. Second, it determined in large part the

cost[1] of the product, which in turn affected the size of the market. The size of the market influenced the scale of production. Third, changes in technology introduced periods when it was relatively easy for new firms to begin operation. In some cases the new entrants brought fresh ideas both of a technical and organizational nature which greatly influenced the future structure of the industry. Therefore, changes in technology acted as the propellant, the dynamic element, thrusting the industry into new phases of activity and into new forms of organization.

Technological change brought about opportunities for ambitious new companies while creating difficulties for firms not amenable to adjustment. The change from the daguerreotype to the collodion process hurt those manufacturers producing daguerreotypes. During the collodion period the only material that could be produced in factories was positive printing paper; however, because these companies were in the metal fabrication business, they found it difficult to take advantage of this new opportunity. Therefore, the photographic industry in the leading daguerreotype producing countries, namely, the United States and France, was particularly hurt by this change; but on

1. Cost is used in the broad economic sense here which would include the simplification of the photographic process itself.

the other hand, it presented an opportunity for paper producers in England and Germany. Since the optical requirements remained the same, camera makers and optical firms were generally unaffected. In the movement from collodion to gelatin plates, the paper industry was not immediately affected, and since there was relatively little other production of photosensitive materials during the collodion era, the dry plate period represented an especially good opportunity for new companies to begin production of photographic materials. However, it brought a period of adjustment for the optical and camera manufacturers because the optical components became less important for the new market which the gelatin emulsions had developed than for photographers of the preceding period; yet the needs of professional photographers for quality products remained fairly constant, easing the adjustment for these firms. The greatest impact of the development of gelatin emulsions was to bring the amateur photographer into the field and thereby to increase demand. This stimulated a change in the scale of production. In addition, it brought relative ease of entry for new firms and, therefore, drew new and ambitious entrepreneurs into the field of production.

Some of these new dry plate firms took the lead in molding the character and structure of the newly revived industry. Dry plate firms moved into production of the

new gelatin emulsion papers, celluloid film, celluloid film cameras, and movie cameras. Once the leading firms had become established, the ease of entry declined. For film photography, the capital and technical requirements were quite demanding and, therefore, made entry into this phase of production very difficult. As a result of the economic pressure due to high capital requirements, patent restrictions, and need for highly technical knowledge, firms already in existence found it advantageous to combine operations in order to derive the benefits of large-scale production, pooling of patents, and capital reserves to help in weathering temporary fluctuations in the market. Therefore it was some of the early dry plate makers who responded to the new technology and in turn began the move toward institutionalization of innovation.

The growth and changing character of the photographic industry influenced technical communication. From 1839 to 1860 information about processes flowed freely, and in only a few cases were these new ideas encumbered by patents. However, journal information on production of photographic papers declined sharply with the rise of albumen paper producers in Germany and England in the 1860's. New processes developed by these firms became trade secrets. Information on other processes remained open, however, until the 1880's, when dry plate manufacturers kept emulsion formulas and other processes secret. New ideas

and inventions became increasingly restricted by patents. The technical journals just prior to such developments as albumen paper, gelatin emulsions, and film photography carried considerable information on these new processes, and this did much to stimulate commercial activity; however, once production was begun, the free flow of information ended, and, therefore, the opportunities for later entrants were lessened.

In the relations between science and the photographic industry, definite national differences emerged. Throughout most of the century German manufacturers tended to have closer contact with science than did their English, French, and American counterparts. From the 1860's a number of German producers such as Kurz, Trapp, and Liesegang were scientifically trained, and they called upon academic chemists for assistance. Because of their own scientific orientation, these producers frequently had small laboratories in their factories. This relationship with science put them in a competitive position in the production of photographic paper and chemicals.

However, the German photographic industry suffered because of its weakness in gelatin dry plate production. As indicated earlier, this weakness probably stemmed in large part from the difficulty in obtaining good quality, inexpensive plate glass. Although German plate manufacturers faced stiff competition from foreign producers during

the last two decades of the century, their close association with science stimulated them to develop high-quality plates and emulsions with extended color sensitivity. Therefore, just as chemical producers and optical firms in Germany came to focus on fine chemicals and precision optics where yields were low and value of product high, the German dry plate companies likewise produced primarily for the most demanding and sophisticated portion of the market. However, since the new entrants into photographic paper and film production in other countries came from firms which had developed a strong financial base in the dry plate business, the economic weakness of Germany's dry plate industry may account for its loss of leadership in paper production and late entry into film production. In view of the strength of the German fine chemicals industry in research and the pressing need of German manufacturers for a competitive substitute for glass, it is surprising that celluloid film for photography was not originally developed in Germany. In the twentieth century Agfa drew upon its research facilities and developed a suitable photographic film but did not reach a strong position in the market until World War I.

While German dry plate producers during the last two decades of the century operated on only a small scale, American, British, and French dry plate firms moved toward

production on a large scale for a mass market. As the amateurs entered the market in increasing numbers, the scale of operations of these firms grew, providing them with the financial reserves necessary to extend their operations into paper and film production. As a result, these leading firms, in particular, the Eastman company, grew into very large companies producing for a mass market.

Though British, French, and American producers of photographic materials did not have an early close association with science as did the German producers, by the end of the century those companies which were in the strongest position economically, Eastman, Lumière, Wratten and Wainwright, and Ilford, were companies that were employing scientifically trained personnel and establishing research laboratories. These companies were beginning to recognize that employment of scientifically trained persons provided certain commercial advantages such as: (1) the lead in product innovation and control of patents; (2) development of more efficient processes for production; and (3) a flexible administration, attuned to new ideas and production methods.

Therefore, in the case of the photographic industry, the state of science and photographic technology determined to a great extent the general pattern of development. The state of science set broad limits within which photographic

technology could move, although some technological advances preceded scientific investigation of the relevant topics. In turn, the state of photographic technology set further limits as to the direction of movement of the photographic industry. It would be a mistake, however, to regard the pattern of development as an outgrowth of the influence of science and technology alone, for the dry plate industry in Germany well illustrates the impact of economic conditions on an industry even where there were very close relations with science and scientists. Therefore, any comprehensive view of development of industry must include the science sphere, the technology sphere, and the economic sphere. Yet in the case of an industry that is science-oriented, the pattern of growth may, like that of the photographic industry, be strongly molded by the character of the technological progress and its dependence on science.

Toward the end of the nineteenth century, the directors of the major firms in the industry had come to recognize that, in order to control to any extent the destinies of their companies, they needed some control of the limiting conditions imposed by economics, science, and technology. In response to the economic sphere, they tended to gain control of raw material suppliers and retail distribution agencies and sought to influence their markets through trademarks and national advertising. In the spheres of science and technology, they responded

by acquiring process and product patents; employing engineers, chemists, and physicists for administration, supervision, and research; and establishing research laboratories.

The research laboratories gradually emerged from the union of two movements during the last half of the century. On the one hand, the aniline dye industry pioneered in establishment of such laboratories during the last third of the century and, therefore, set an example which was followed by the photographic industry, including those firms closely associated with the dye industry such as Agfa, Hauff, and Lumière. On the other hand, laboratories such as those of the Eastman company and Wratten and Wainwright gradually emerged from small plant laboratories where the owner tended to try new ideas by trial-and-error methods. Therefore, through the establishment of research laboratories, the leading photographic firms sought to institutionalize innovation and thereby further rationalize their business.

It was indeed fitting that it was Arago, one of the leading scientists of the day, who, on August 19, 1839, announced for the first time the details of the daguerreotype process to an overflow crowd attending a joint session of l'Académie des Sciences and l'Académie des Beaux-Arts in Paris. Both before and after this moment of introduction, photography in the nineteenth

century depended upon the support of scientifically trained personnel. While the industry and technology in general found declining interaction with science during the third quarter of the century, the introduction of chemists into the growing industry during the last two decades brought a revival of contact between chemistry and photographic technology. By 1900 it had become almost an economic necessity for a large competitive firm to have its own research facilities and to employ scientifically trained personnel. On the other hand, it was already evident from the work of investigators such as Andresen, the Lumières, Seyewetz, Hurter, and Driffield that the relationship between science and the photographic industry was not to be totally one-sided, but that a limited degree of feedback in the form of basic scientific discovery would also come from these newly established industrial laboratories. Arago's announcement represented only a foreshadowing of a partnership between science and technology which benefitted each partner and exerted a strong influence on the photographic industry in the nineteenth century.

APPENDIX

Construction of Tables

The information supplied in the Tables accompanying this study came from raw data from two sources: (1) statistics on the photographic industry from the Bureau of Census reports in the years 1879, 1889, 1899 and 1904; (2) statistical material collected from a survey of city directories for those cities listed by the census as having photographic materials or apparatus companies from 1879 to 1904. The results of this survey compared with the census information show the following degree of coverage:

	1879	1889	1899	1904
Percent of firms included in survey	67	62	69	68
Percent of total value of production of firms included in survey	64	72	81	92

The sample is biased in favor of firms in metropolitan areas and those of substantial size. Nevertheless, such a survey provides some indication of trends and their movement between census years. All raw data from the census statistics was subjected to adjustments for price changes (with separate consideration for capital and production within industrial categories) and expressed in 1929 dollars. Most useful for adjustments were Creamer,

Dobrovolsky, and Borenstein's _Capital in Manufacturing and Mining_ (NBER) and William Shaw's _Value of Commodity Output Since 1869_ (NBER). Also consulted were Edwin Frickey's _Production in the United States, 1860-1914_ and _Historical Statistics of the United States, Colonial Times to 1957, A Statistical Abstract Supplement_, published by the Bureau of the Census.

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Ann. chim. phys.	Annales de chimie et de physique
Ber. Deut. Chem. Ges.	Berichte der Deutschen Chemischen Gesellschaft
Brit. J. Photog.	British Journal of Photography
Compt. rend.	Comptes rendus hebdomadaires des seances de l'Académie des Sciences
Edinburgh Phil. J.	Edinburgh Philosophical Journal
Journals Roy. Inst.	Journals of the Royal Institution
Phil. Mag.	The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science
Phil. Trans. Roy. Soc. London	Philosophical Transactions of the Royal Society of London
Photog. J.	The Photographic Journal
Photog. N.	Photographic News
Photog. Korresp.	Photographische Korrespondenz
Photog. Mit.	Photographische Mitteilungen
Proc. Roy. Soc. London	Proceedings of the Royal Society of London

1. Based on principles of *Chemical Abstracts*.

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